N83-28060

SOC-SE-03-01

Volume V

Cost Benefits
and Programmatic
Analyses

April 1983

SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY—FINAL REPORT

Approved by:

Sherman Schrock
Program Manager

MARTIN MARIETTA AEROSPACE
DENVER AEROSPACE
P.O. Box 179
Denver, Colorado 80201

Page intentionally left blank

Page intentionally left blank

FOREWORD

This final report, submitted to National Aeronautics and Space Administration (NASA) Headquarters, Washington, DC 20546, presents the results of the Space Station Needs, Attributes and Architectural Options Study performed by the Space and Electronics Systems Division of the Martin Marietta Corporation under NASA Contract NASW-3686.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

CONTENTS

VOLUME V COST, BENEFITS AND PROGRAMMATIC ANALYSIS

CONTENTS (Con't)

VOLUME V COST, BENEFITS AND PROGRAMMATIC ANALYSIS

VOLUME V COST, BENEFITS AND PROGRAMMATIC ANALYSIS (Con't)

FIGURES (Con't)

VOLUME V COST, BENEFITS AND PROGRAMMATIC ANALYSIS (Con't)

TABLES

VOLUME V COST, BENEFITS AND PROGRAMMATIC ANALYSIS (Con't)

1.0 INTRODUCTION

1.1 PURPOSE

The cost, benefits, and programmatic analysis task for this study had two major objectives. The first was to aid in the selection of a space station system architecture. This was accomplished by determining the marginal costs and benefits of each capability increment, and evaluating the relationship between the demand for new capabilities and the affordability and availability of those capabilities.

The second major objective of this task was to estimate the cost and schedules for the program option selected.

1.2 SCOPE

The costs, benefits and schedules presented in this volume are limited to space station elements. This includes the modules of the manned space station, the dedicated teleoperator maneuvering systems, dedicated orbital transfer vehicles, and payload platforms. The development cost of the TMS and the OTV is not included in the Space Station cost estimate.

The primary purpose of this study was to identify, collect, and analyze the science, applications, commercial, U.S. national security and space operations missions that would require or be materially benefited by the availability of a permanent manned space station in low earth orbit and to identify and characterize the space station attributes and capabilities which will be necessary to satisfy these mission requirements. Emphasis is placed on the identification and validation of potential users, their requirements, and the benefits accruing to them from the existence of a space station, and the programmatic and cost implications of a space station program. Less emphasis has been placed on detailed design beyond that necessary for the identification of system attributes, characteristies, implementation approaches and architecture options, and ROM costs.

The study results are presented in six volumes as follows:

Volume I presents an executive summary highlighting the specific results obtained during each phase of the study as described in Volumes II through VI (classified information excepted).

Volume II presents the results of our mission definition activities including the identification, modeling and validation of potential user missions, their requirements and the benefits that could accrue to the users from the existence of a space station.

Volume III presents the space station user requirements, their integration and time phasing, and the derivation of system and user accommodation requirements. The derivations of user requirements and space station accommodations encompassed a traceability analysis, parametric studies, and an analysis of economic, performance, and social benefits afforded by the existence of a space station.

Volume IV presents the results of our study efforts describing our analyses and defining our recommended space station implementation approaches, architecture options, and evolutionary growth.

Volume V presents the affordability analysis conducted to determine the affordable mission model, quantification of economic benefits, estimate of the ROM costs for each of the architectural options and their associated program and element schedules.

Volume VI presents the results (classified) or oiuf analysis for the DOD National Security mission. This volume was published under a separate cover and is available through the DOD Task Manager at Space Division (SDXR), Los Angeles, California.

2.0 EXECUTIVE SUMMARY

2.1 PROGRAM DESCRIPTION

Our architecture option studies have lead to a series of major architectural decisions which resulted in three Space Station configurations. Two modular Space Station configurations were developed, one based on STS Shuttle cargo bay delivery, and the other making use of the cargo bay plus the additional volume afforded by the external tank/aft cargo carrier. A third configuration is based on the shuttle derived vehicle concept.

Our cargo bay (14' diameter) modular design is based on the premise of maximizing commonality between elements and the logic of phased growth. Highlights of the approach include: STS compatibility, commonality, a phased growth approach, and having allowances for unplanned future growth.

An aft cargo carrier concept (ACC) was developed after it became apparent that the STS transportation costs involved with building the station were appreciable and that many of the STS payloads are volume limited. The ACC approach provides additional volume (12,000 ft^3) which not only permits the transportation of extra elements on a single STS flight, it also allows for elements up to 25 feet in diameter. With this approach at least two STS flights involved with building the station can be saved.

A Space Station configuration based on the shuttle derived vehicle payload carrier permits savings of 3-5 STS flights, and achieves a large pressurized volume (mature station requirement) in a single launch. Advantages associated with the SDV station are: reduced transportation costs, significant early capability, and crew safety at the initial phase. Reduced growth capability and a commitment to the launch era technology are potential disadvantages.

A limited amount of time was spent on platform designs, but the major conclusion is that the selection of five to six platforms including two (astronomy and materials processing) that are colocated with the space station would be cost effective.

2.2 Program Affordability

An important part of our programmatics task was the affordability analysis. Consideration of affordability is important in two major areas; the science missions that will occur in the 1990's and the development and building of the space station.

In order to develop realistic user requirements for a space station it was necessary to establish a realistic affordable mission model. We started with the Composite Mission Model presented at the mid-term review as the comprehensive set of missions that the user community desired to conduct given that no budget constraints exist. We then determined the subset of those missions that were affordable within the limits of projected NASA budget allocations.

The approach we used to determine an affordable mission model was to first review NASA budget history to determine the trend of both total budget and budget allocations to the continuing programs and new starts. We found that a ten year average NASA budget in fiscal year 1984 dollars was $7.2 billion. We set $7.2 billion as a target budget ceiling for our affordability analyses.

Our next step was to determine the budget allocations by major programs and extrapolate these into the future using the groundrules and assumptions presented at the end of this section. We used an early ROM estimate of a space station program cost as a strawman budget allocation and then refined it as our space station cost estimates matured. In this manner we determined the budget allocations by mission category out to the year 2000. These budget allocations are shown in Figure 2.2-1 NASA Budget Projection. We then matched the individual mission funding requirements to these budget allocations to determine an affordable mission set to the year 2000.

2.3 Program Economic Benefits

A permanent manned Space Station in low Earth orbit will provide cost-effective space operations as well as capabilities to support DOD missions and new space industries. Our studies have identified the following principal economic benefits:

1) A manned Space Station will enable the conduct of space missions and their respective operations with fewer Shuttle flights. Satellite servicing, for example, can be completed without scheduling a dedicated Shuttle flight for each servicing mission. Service equipment can be based at the Space Station instead of being transported to and from orbit for each use. In addition, automated systems for servicing of spacecraft in geosynchronous orbit will provide timely response in the event of unexpected spacecraft failures.

2) The benefits derived from LEO and GEO delivery missions are potentially very significant. The combination of using Shuttle and Space Station will allow increased efficiency in manifesting compared to using Shuttle alone. This improved manifesting will reduce the number of STS flights to deliver LEO and GEO payloads.

3) A Space Station will provide a cost effective basing mode for user payloads by providing utilities such as structure, attitude control, power and thermal control. This basing benefit results from either attachment to the manned Space Station or one of the platforms that are a part of the Space Station architecture. These services would otherwise be provided by free flyers that each user would have to design and build independently.

A major objective of the economic benefits analysis was to aid in the selection of program options and Space Station architectures. The benefit to cost ratios of each program option were compared and as a result we concluded that a single manned Space Station had a better benefit to cost ratio than multiple stations.

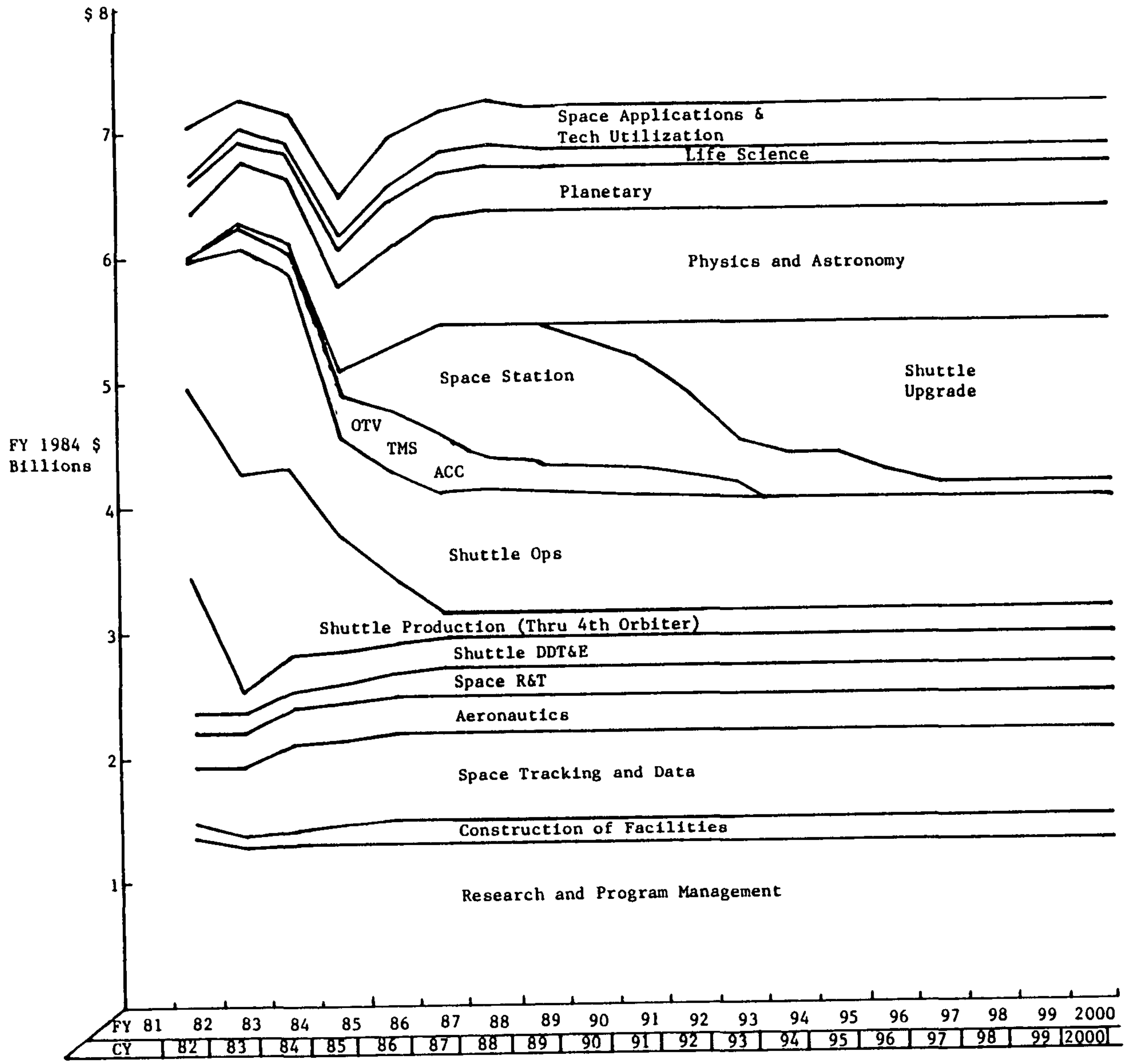


Figure 2.2-1 NASA Budget Projection

The next step in our selection process was to determine the most cost effective orbital inclination to locate the manned Space Station. Space Station mission analysis studies identified inclinations of 28.5°, 57° and 70° as the most promising inclinations (reference Volume 3, Section 6.0). The optimal inclination of 28.5° was selected because it had the highest benefit/cost ratio. Economic benefits from delivery, servicing, basing, assembly and operations were determined by comparing performance of the missions with Shuttle alone and with Space Station.

A summary of the economic benefits by Space Station inclination is presented graphically in Figure 2.3-1 Economic Benefits by Inclination. For example, the economic benefits of GEO delivery from a 28.5° station results in "value added" of $6400 million. This indicates that if dedicated STS flights were used to make all GEO deliveries in our Affordable Mission Model it would cost $6400 million more than to make these deliveries from a 28.5° Inclination Space Station. Figures 2.3-2 Cumulative Economic Benefits - Modular Space Station 28.5 and 2.3-3 Cumulative Economic Benefits - SDV Space Station 28.5 display graphically the cumulative economic benefits.

2.4 Program Costs

Our estimates of space station costs from ATP through 10 years of evolution and operation are shown in Table 2.4-1 for each of the three architectural options as described in section 2.1 Program Description.

Space station costs by evolution increment are shown in Figures 2.4-1 and 2.4-2 for a modular concept and a Shuttle Derived Vehicle concept respectively. The plot of cost versus fiscal year is cumulative cost and includes design development, test and evaluation costs, production costs, initial launch costs, and operations costs. The costs for a modular concept apply to either an STS orbiter modular concept or to an ACC modular concept. The preliminary ROM nature of the cost analysis combined with the early conceptual design data available at this time does not indicate a significant difference in the development or production cost of the modular options.

The SDV concept however does permit cost avoidance in the areas of structure design, fabrication, and assembly and system test and integration. A significant cost avoidance is realized in launch costs if an SDV vehicle is used to launch the SDV space station module. The space station costs were estimated parametrically by element. Our parametric analysis used cost estimating relationships (CERs) from the Martin Marietta Cost Analysis Data Books (CADBs). These CERs are based on similar major programs such as Skylab and Shuttle.

Launch costs are based on an average cost per flight in the early 1990s of $47.4 million in FY 1975 dollars or $110 M per flight in 1984 dollars for a launch from KSC. These costs are based on a 24 flight per year mission model using 4 orbiters. Launch costs from VAFB at a 6 flight per year rate would be $66.3 million in FY 1975 dollars or $150 million in FY 1984 dollars.

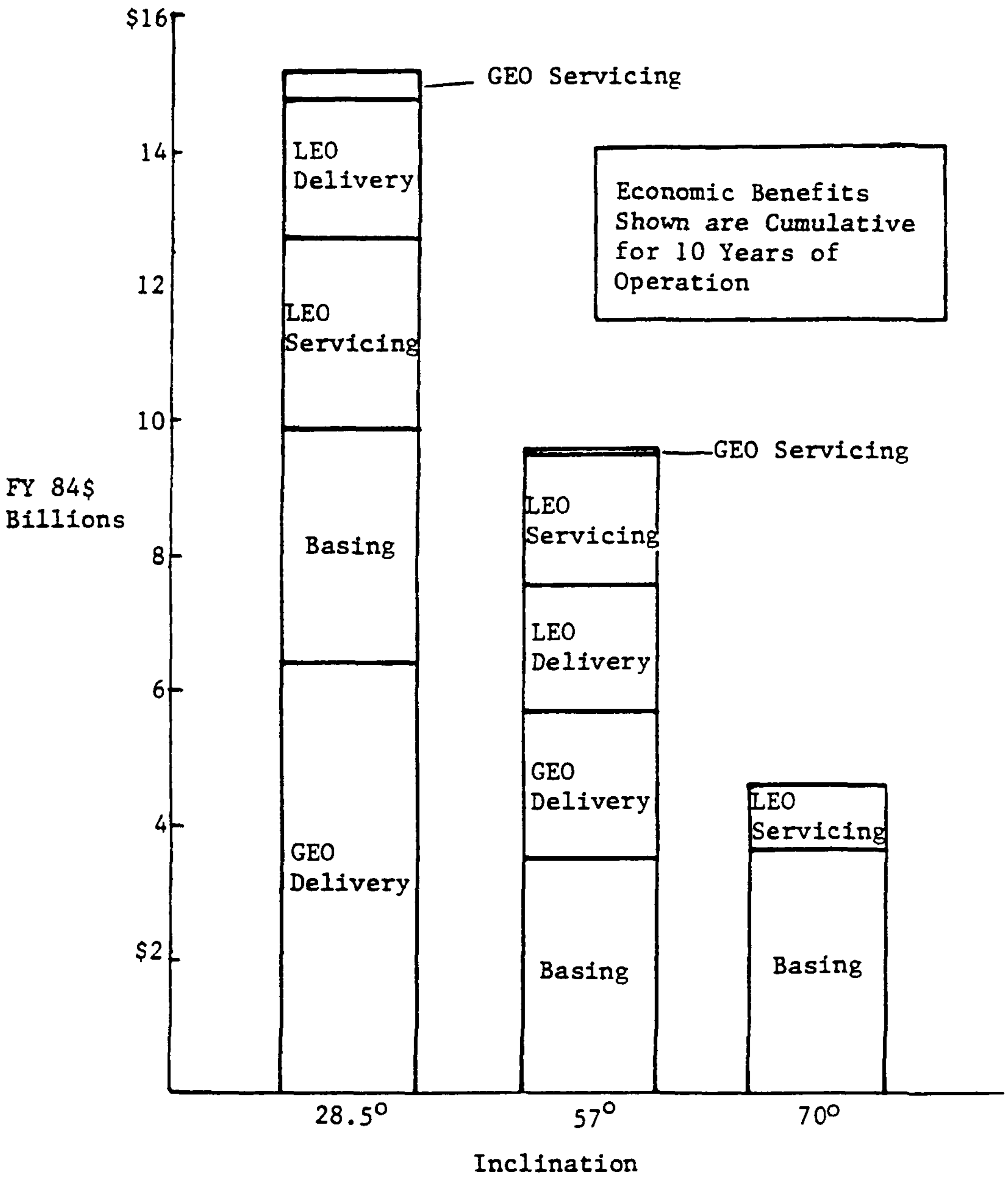


Figure 2.3-1 Economic Benefits by Inclination

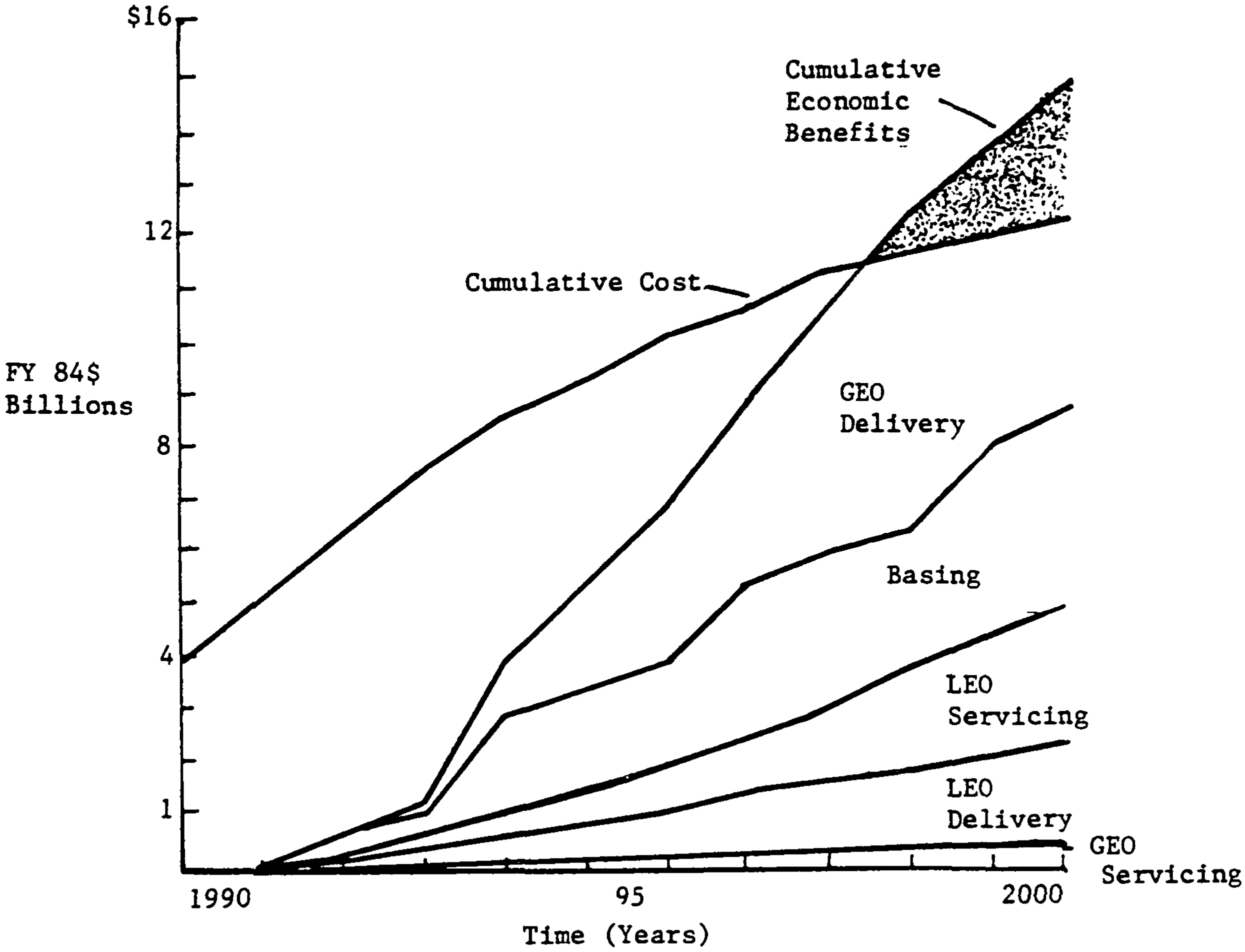


Figure 2.3-2 Cost/Benefit Breakeven Analysis-Modular Space Station 28.5°

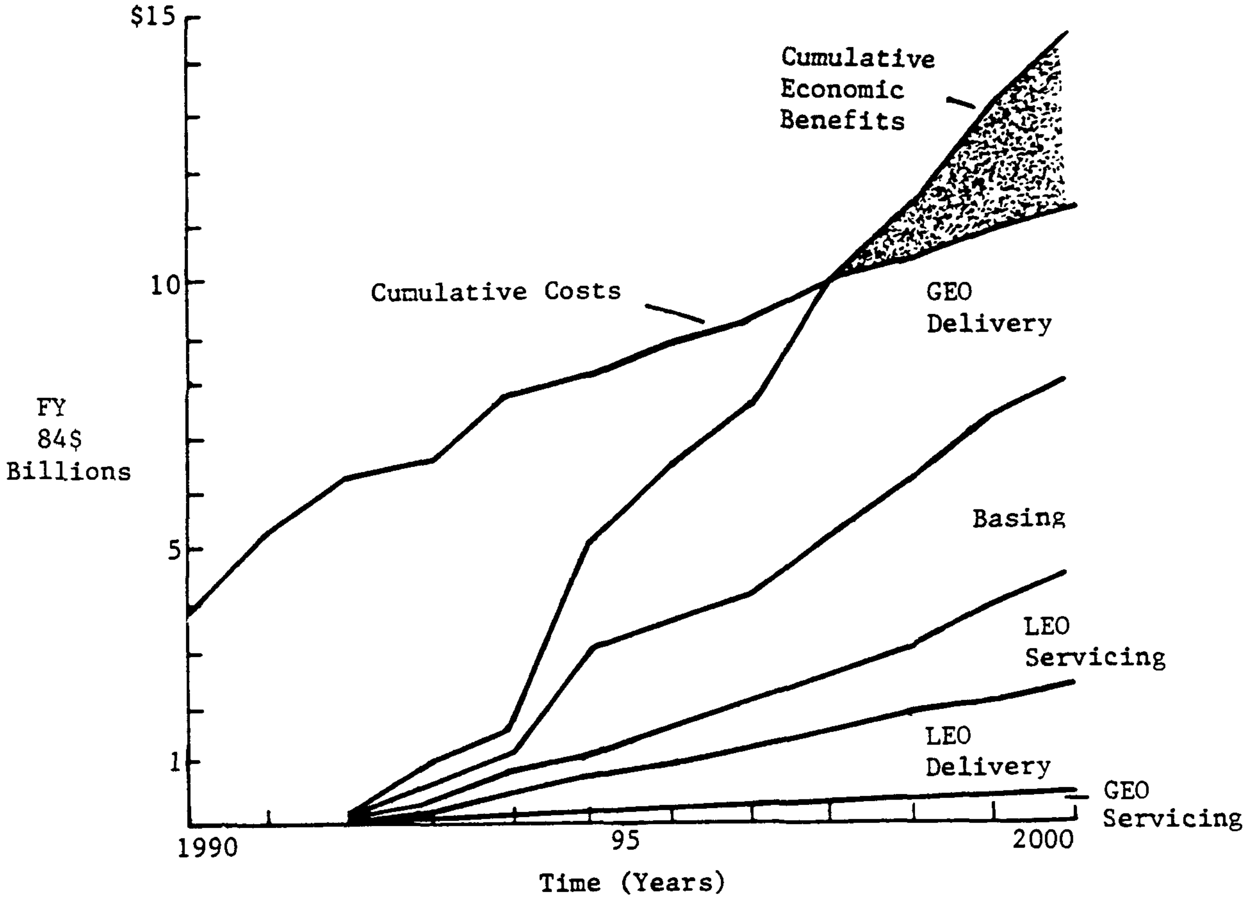


Figure 2.3-3 Cost/Benefit Breakeven Analysis-SDV Space Station 28.5°

Table 2.4-1 Summary Cost by Architectural Option

	Cost FY84 $ In Millions				
Option	DDT&E	Prod.	Launch	Ops	Total
Modular 14' Diameter	$2470	$5255	$2030	$2520	$12,275
Modular ACC	2470	5255	1810	2520	12,055
Shuttle Derived Vehicle	2430	5135	1370	2520	11,455

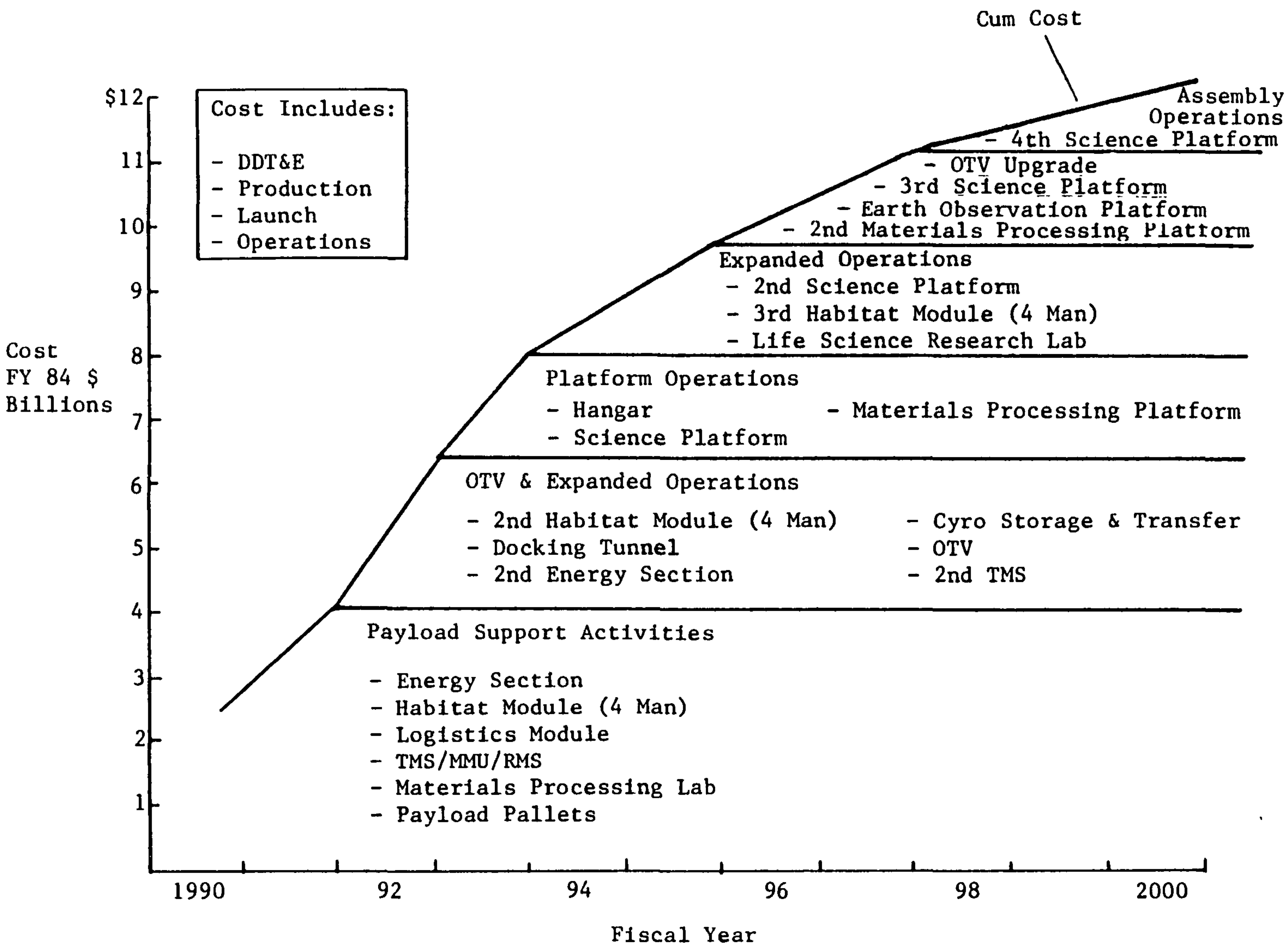


Figure 2.4-1 Space Station Cost by Evolution Increment - Modular Concept

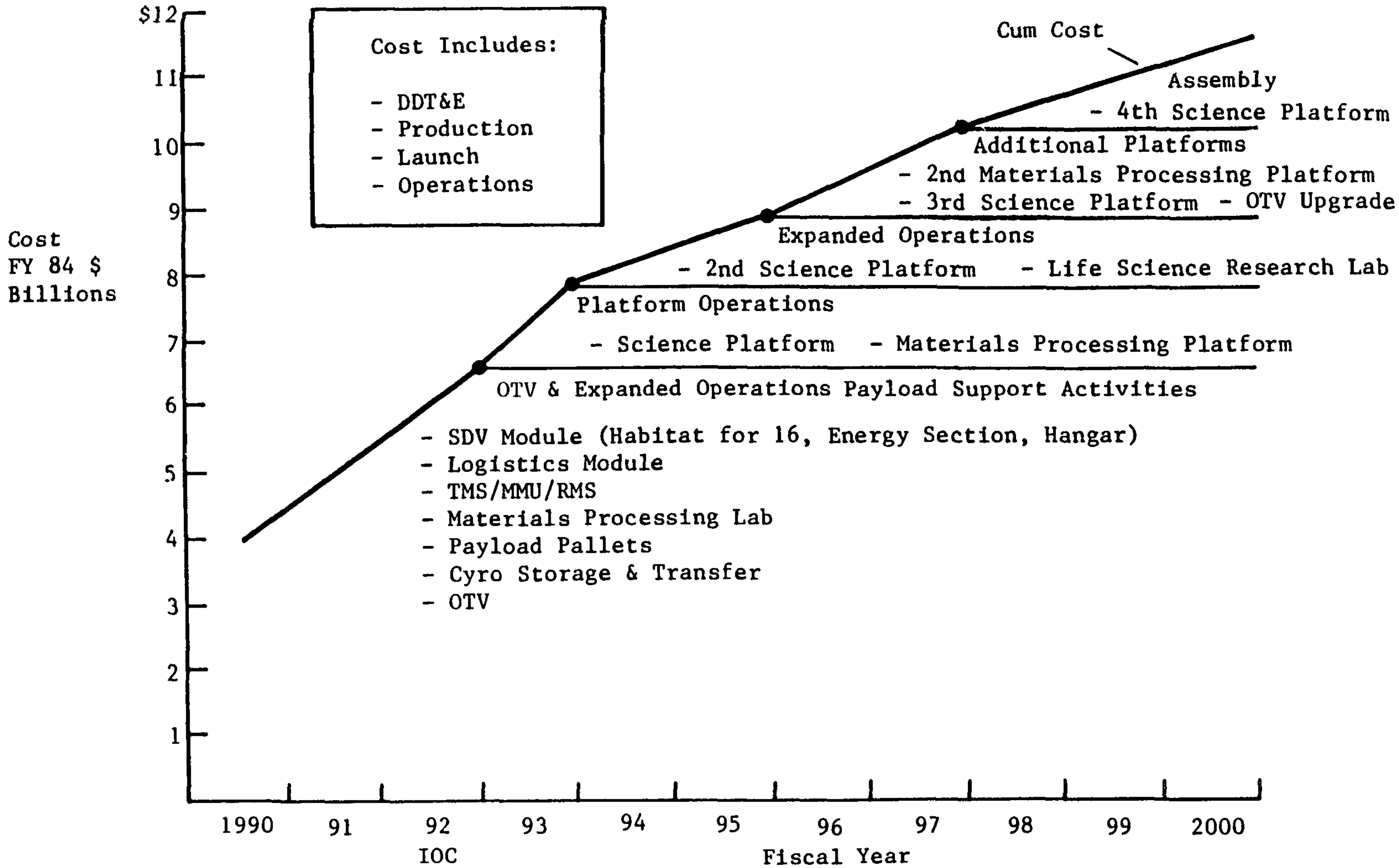


Figure 2.4-2 Space Station Cost by Evolution Increment - SDV Option

Operations costs were assumed to be equal for any of the concepts since crew size would be evolved at the same rate for each concept. Operations costs include the cost of shuttle resupply flights on a cost share basis, replacement spares cost, consumables and a ground and flight crew of 100 people.

2.5 Program Schedules

The schedules in this section represent our best judgment of development, test, fabrication and assembly span times for the space station program as described in Section 2.1 Program Description. They are based on analogy to Skylab and other major development programs but modified to fit our ground rules and assumptions for this program.

The summary program schedule was developed after preparing individual schedules for space station elements. The habitat module development schedule is the critical path to space station initial operational capability.

The key program assumptions that drive element schedules are that critical technology development would be completed before authority to proceed (ATP) on space station elements and a protoflight approach will require refurbishment time after development test is complete.

The program and element schedules in this section are shown by fiscal year (eg. FY1, FY2) as requested by the NASA starting with ATP for a phase C/D development.

The Space Station program development schedule shown in Figure 2.5-1 summarizes the major activities and milestones required for space station development thru initial operational capability (IOC). The span times from ATP to Preliminary Design Review (PDR) and Critical Design Review (CDR) are typical for a large scale program such as this. The span from CDR to IOC is longer than a program with separate development and flight articles due to the required time to refurbish or replace components after qual and development tests. This protoflight approach adds about four to five months to the program schedule but we think the resultant cost avoidance of duplicate flight type hardware is a cost effective trade off.

The evolution of the space station is shown in Figure 2.5-2. This schedule shows the build up of the space station by element. The span times by element are from ATP for that element to launch of the element.

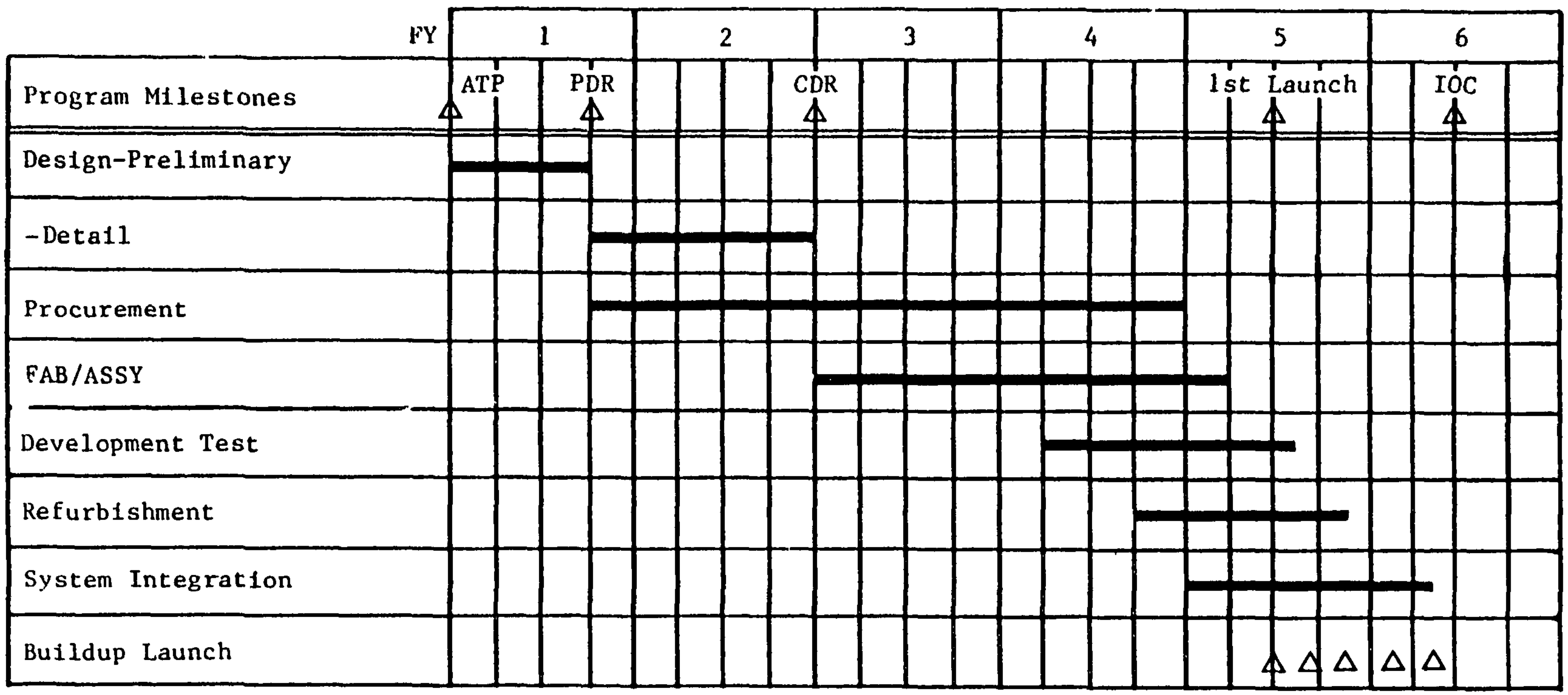


Figure 2.5-1 Space Station Program Development Schedule

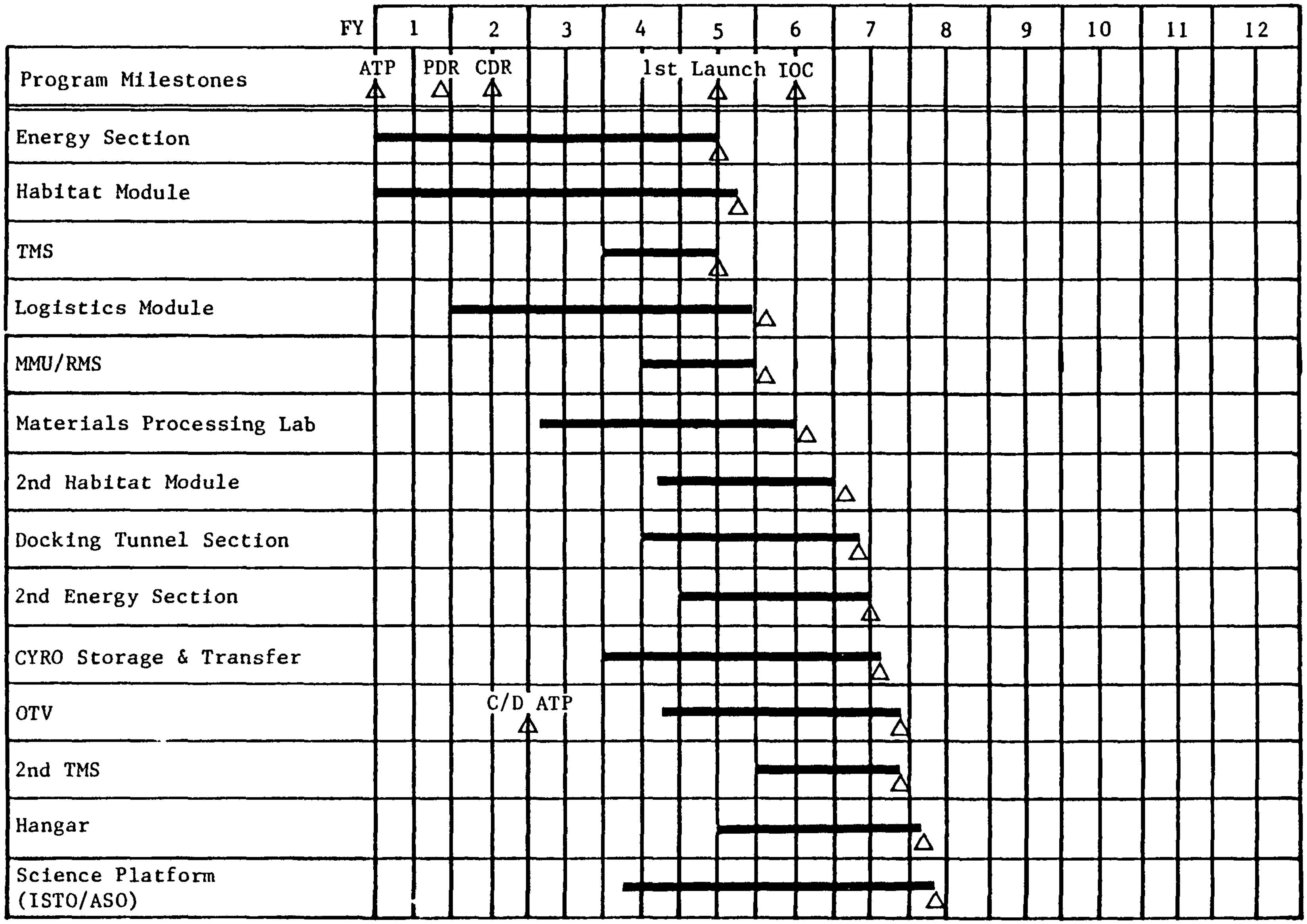


Figure 2.5-2 Space Station Program Evolution Schedule

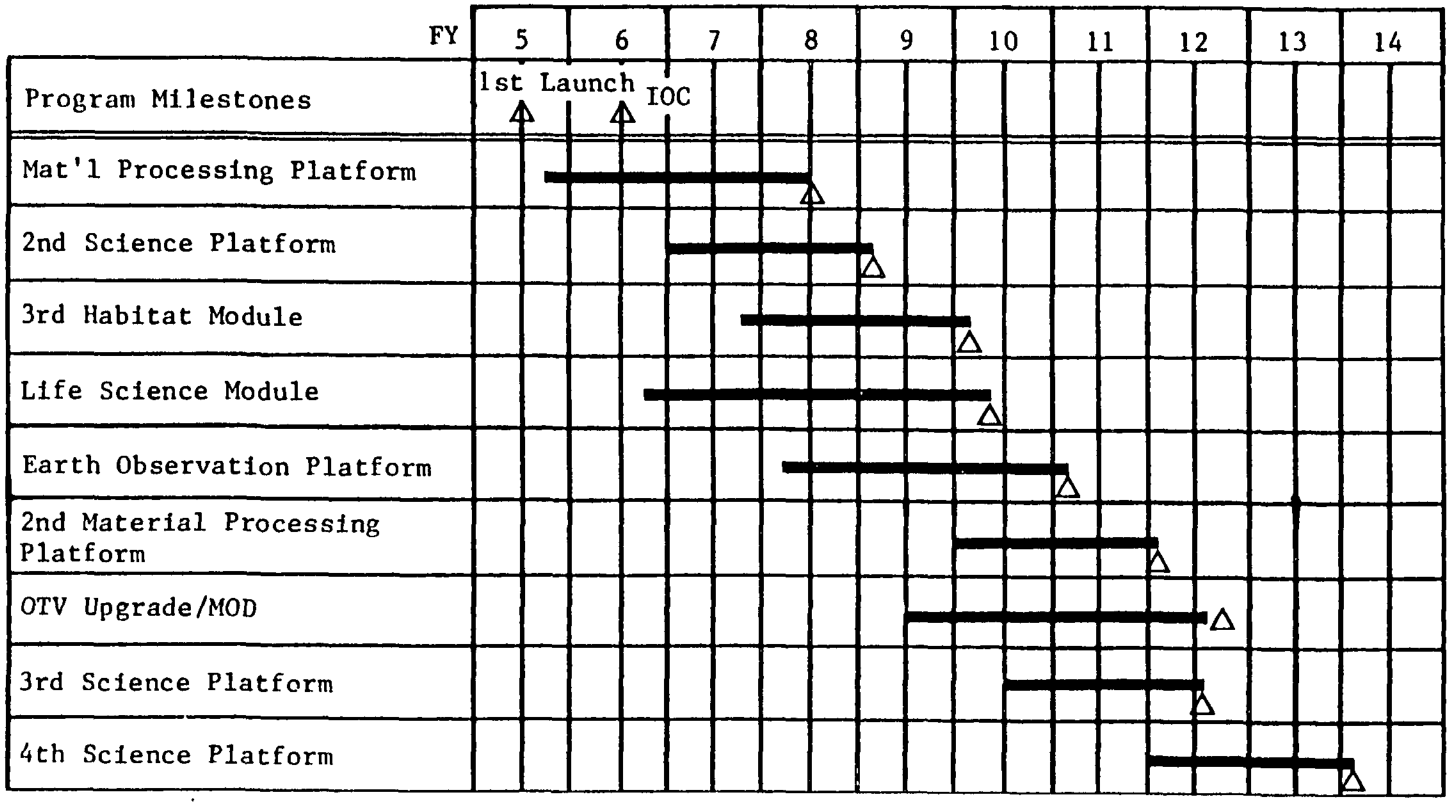


Figure 2.5-2 Space Station Program Evolution Schedule (Cont.)

2.6 RECOMMENDATIONS AND CONCLUSIONS

This programmatics task has presented several major conclusions concerning the development and evolution of a space station.

Its Affordable

We have found that both the acquisition of a space station and the accomplishment of NASAs science and technology objectives are affordable within the projected budget constraints. The affordability analysis was performed to determine an affordable mission set from the total compliment of missions that the science community desired to accomplish. The budget constraints necessitated delaying lower priority science missions until funds would be available. The overall effect of including a space station as an orbiting NASA asset is to provide a greater return of science dollar spent by extending on-orbit data collection time.

Its Beneficial

The economic benefits analysis shows that the space station will be cost effective as a space launch base and as a platform for user missions. As a launch base, it has the potential to eliminate the need to buy two additional orbiters that would otherwise be required to handle the projected volume of affordable launches planned in the 1990s. By providing utilities and subsystems to users, the space station will eliminate the need to design and build approximately 40 independent free flying space craft. As an experimental laboratory it will provide low cost continuous time on orbit to shuttle sortie missions that would otherwise be limited to several days on orbit.

The space station as a repair base will enable guick response low cost repair and servicing of satellites to extend their useful life and improve their return on science or investment dollars.

It Pays for Itself

The cost/benefit breakeven analysis indicates that the space station will pay for its acquisition cost in the value it adds to the Space Transportation System. The potential economic advantage as a space transportation node indicates that it can avoid as much as $11.6 billion in FY 1984 dollars. The potential avoidance of each user mission providing their own independent space craft bus shows a $3.6 billion advantage to the space station and its associated platforms.

A Reusable OTV Is Needed

Our benefits analysis indicate that a significant advantage of space station is to serve as a launch base for high energy missions. A reusable, space maintained OTV is a necessary element of this scenario to make it cost effective compared to expendable vehicles. The major advantage to a space reusable OTV is that it would not be launched to low earth orbit on each shuttle thus saving space for payloads and reducing total transportation cost to the user.

A Reusable TMS Is Needed

Just as the reusable OTV benefits the transportation of missions to high energy orbits, the TMS vehicle enables delivery and servicing of payloads in orbits near the space station at a significantly reduced cost over a TMS that accompanies shuttle. Again, the major advantage is the launch weight and volume saved if a TMS remains based in orbit at a space station.

Recommendations

We recommend that limited near term NASA funds should be allocated not only to space station technology studies but also to studies to develop on orbit based and maintained, reusable OTV and TMS vehicles. Our study results show these two elements of a space transportation system are necessary to cost effective operation of a space station.

3.0 PROGRAM DESCRIPTION

3.1 APPROACH

The Space Station program defined in this section is one that is evolutionary in capability and affordable within the constraints of the projected NASA budget.

We have assumed a low cost protoflight approach to program development. We do not feel this space station program can afford the multiple test and backup articles that were built for Skylab. We have assumed that space station launch processing will be treated like any other payload on shuttle.

In its operational phase the manned space station will operate autonomously as does any other payload. The manned station would require very minimal support and monitoring from the ground during routine operations.

Our demand analysis shows a need for a manned orbiting space station in the late 1980s. Affordability therefore is the prime constraint on station development.

3.2 PROGRAM EVOLUTION

3.2.1 Evolution Plan

A detailed evolution plan has been developed for the recommended space station program option, the manned station operating at 28.5° in conjunction with several unmanned platforms. The proposed evolution plan is presented graphically in Figure 3.2.1-1. The following commentary will present supporting rational on a year-by-year basis.

a. 1990 — Implementation of unmanned station elements is initiated in the second half of 1990 with delivery of the energy section, habitability module including a category II health maintenance facility (HMF), and a TMS. For the SDV architectural option, delivery of these items would be delayed and combined in a single launch with the items implemented in 1991.

b. 1991 — Space station IOC will occur early in 1991 with delivery of a logistics module, MMU, servicing robotics, and the initial crew of four people.

Following station checkout and a brief learning period, scientific payloads will be delivered for attachment to and operations from the station. These payloads include:

1. SAR/Passive Microwave (Earth Observ.)
2. Imaging Spectrometer (Earth Observ.)
3. Satellite Calibration (Earth Observ.)

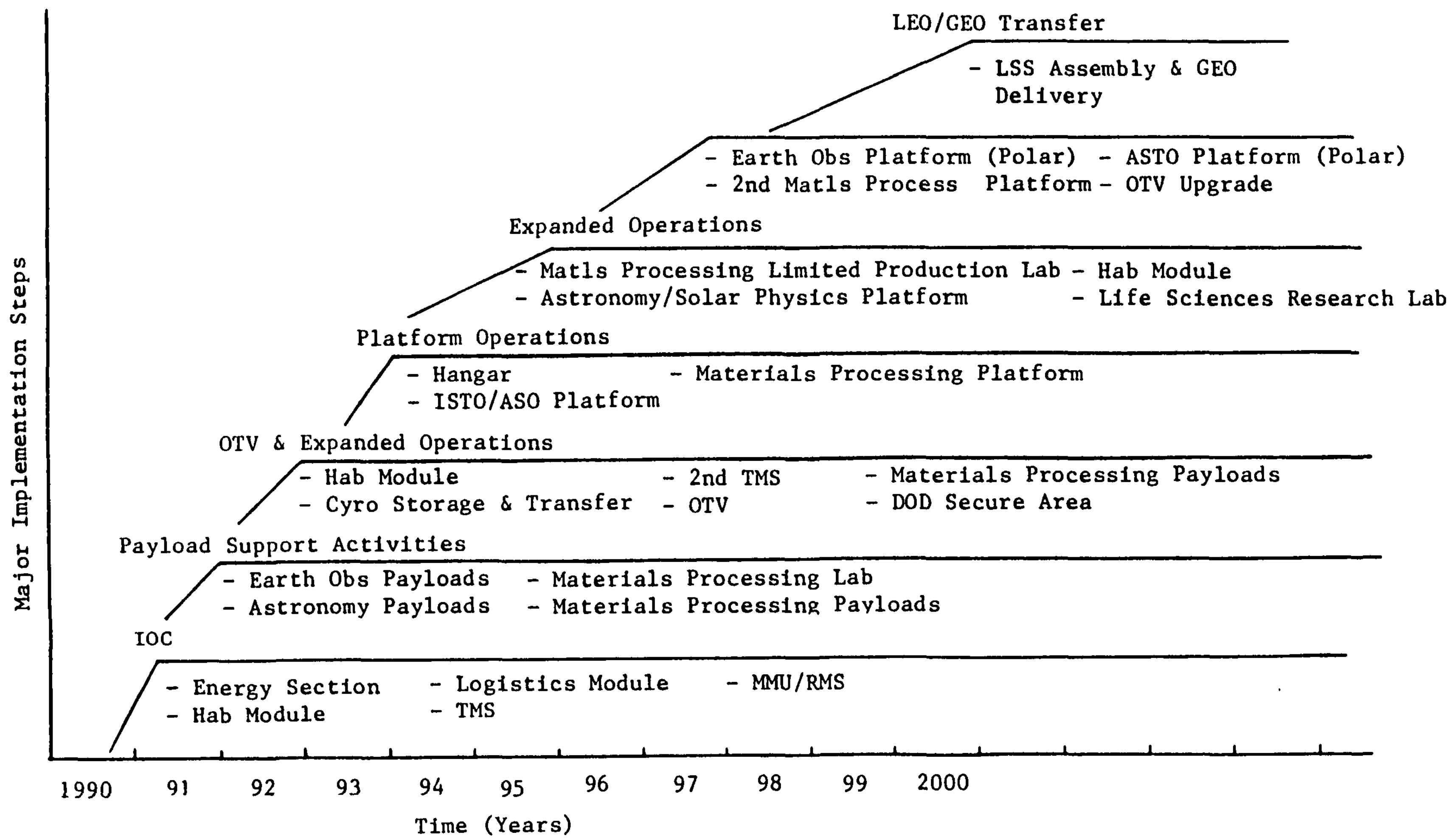


Figure 3.2.1-1 Recommended Evolution Plan

4. Solar Optical Telescope (Solar Physics)
5. Solar Soft X-Ray Telescope Fac. (Solar Physics)
6. Starlab (Astronomy)
7. SIRTF (Astronomy)
8. Space Plasma Effects (Space Physics)
9. EOS (Materials Processing) (2)

Toward the end of 1991, a materials processing (MP) laboratory will be implemented for MP research and development activities. Servicing and resupply of earlier free flying MP payloads operating in a 28.5° orbit will also be initiated using the TMS.

c. 1992 In preparation for the initiation of OTV operations, a cryogen storage tank and a second TMS will be implemented. Because of the crew support for OTV operations, a second habitability module is implemented, followed by the retrievable OTV; and OTV delivery of NASA and DOD payloads to LEO and GEO will begin during the third quarter of the year.

An additional 2 MP payloads will be supported on the station for a total of four.

With availability of the OTV and associated increased DOD operations, it may be necessary to add a secure area or module at this time.

The high level of activity scheduled for this year precludes implementation of a hangar until early 1993.

The OTV activities will continue in subsequent years at a level of 1 or 2 OTV missions monthly.

d. 1993 Early in this year, hangar assembly will begin and continue intermittently through much of the year, interspersed with other activities.

The combined ISTO/ASO platform will be implemented at a 57° orbit, with future servicing support from the 28.5° station via OTV transfer.

A MP platform and MP payloads will be implemented and begin operations in the vicinity of the station, and regular TMS resupply missions will be intiated.

e. 1994 The MP laboratory will be expanded to include a limited production facility which will allow increased production for the more promising processes without full commitment to a complete payload.

An Astronomy/Solar Physics platform will be implemented and operate in the vicinity of the station with continuous communications possible between the two. The platform will support four astronomy and four solar physics payloads between 1994 and 2000.

f. 1995 A life sciences research module will be implemented to conduct plant and animal experiments. A third habitability module will be implemented to accommodate a total crew of 12 people.

g. 1996 A dedicated Earth Observations platform will be implemented in a polar orbit, and will be integrated and supported by the STS since our recommended OTV will not be capable of 28 to 90 orbit plane transfer.

h. 1997 A second MP platform may be required at this time to accommodate commercial payloads whose processes were previously developed in he MP laboratory and limited production facility. This platform will operate in the vicinity of the station and be supported with regular resupply missions using a TMS.

An OTV upgrade may be appropriate at this point to either increase payload delivery capability or to add a thrust control capability which will allow the OTV to carry sizable, but flexible payloads or platforms from LEO to GEO.

The ASTO space physics platform will be implemented in a polar orbit and receive further support from the STS.

i. 1998 The earth observations Passive Microwave payload will require on-orbit assembly support at or near the space station, and will be transported to GEO by the OTV.

At about this point in time, crowding of the available GEO communications satellite orbit may require assembly of a multi-payload platform at the station and subsequent OTV delivery to GEO.

j. 1999-2002 During this period, the GEO-STO space physics platform will require assembly at the station and OTV delivery to GEO.

Similar support will be required by the space physics Very Large Radar.

3.2.2 Program Architectural Options

The architecture option studies resulted in a series of major architectural decisions, the presentation of three Space Station configurations, and a cursory overview of the space station platform concept.

Working from the top level "given" requirements and the space station mission model results, key trade studies issues, architecture related, were identified. Recommended approaches were selected based on both subsystem analysis and rationale derived herein. These decisions were then utilized as a common basis for the configuration development.

Two modular Space Station configurations were developed, one based on STS cargo bay delivery, and the other making use of the cargo bay plus the additional volume afforded by the external tank/aft cargo carrier. A third configuration is based on the shuttle derived vehicle concept.

Our cargo bay (14' diameter) modular design is based on the premise of maximizing commonality between elements and the logic of phased growth. Figure 3.2.2-1 illustrates the modular design at a mature development stage (approximately 1995). Highlights of the approach include: STS compatibility, commonality, a phased growth approach, and having allowances for unplanned future growth. The major disadvantages associated with this design are: the number of STS flights required to reach a mature configuration, and the complexity involved with the buildup and assembly.

An aft cargo carrier concept (ACC) was developed after it became apparent that the STS transportation costs involved with building the station were appreciable and that many of the STS payloads are volume limited. The ACC approach provides additional volume (12,000 ft^3) which not only permits the transportation of extra elements on a single STS flight, it also allows for elements up to 25 feet in diameter. Figure 3.2.2-2 presents this configuration. With this approach at least two STS flights involved with building the station can be saved. Other advantages include the use of larger diameter building blocks and retaining the phased growth approach. This configuration also is capable of future growth. ACC disadvantages include the buildup complexity previously mentioned, and the cost of developing a new module size.

A space station configuration based on the shuttle derived vehice payload carrier is illustrated in Figure 3.2.2-3. This unique approach permits a savings of 3-5 STS flights (buildup phase), and achieves a large pressurized volume (mature station requirement) in a single launch. Advantages associated with the SDV station are: reduced transportation costs, significant early capability, and crew safety at the initial phase. Reduced growth capability and a commitment to the launch era technology are potential disadvantages.

A limited amount of time was spent on platform designs, but the major conclusion is the selection of five to six platforms including two (astronomy and materials processing) that are colocated with the Space Station. A preliminary design approach would be to use the MSFC space platform design concept, since compatibility exists between the Space Station platform requirements and the space platform capabilities.

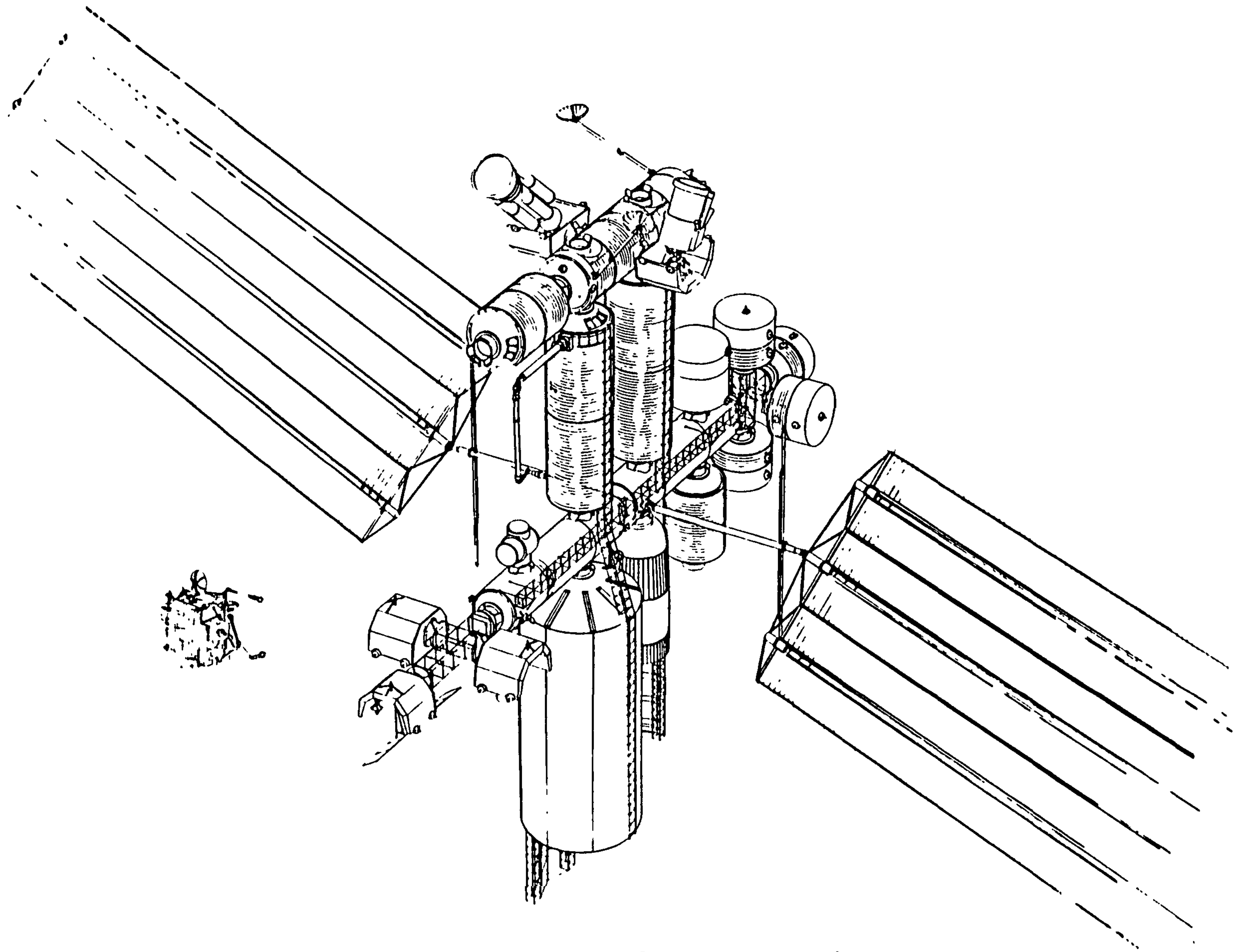


Figure 3.2.2-1 14' Diameter Modular Space Station

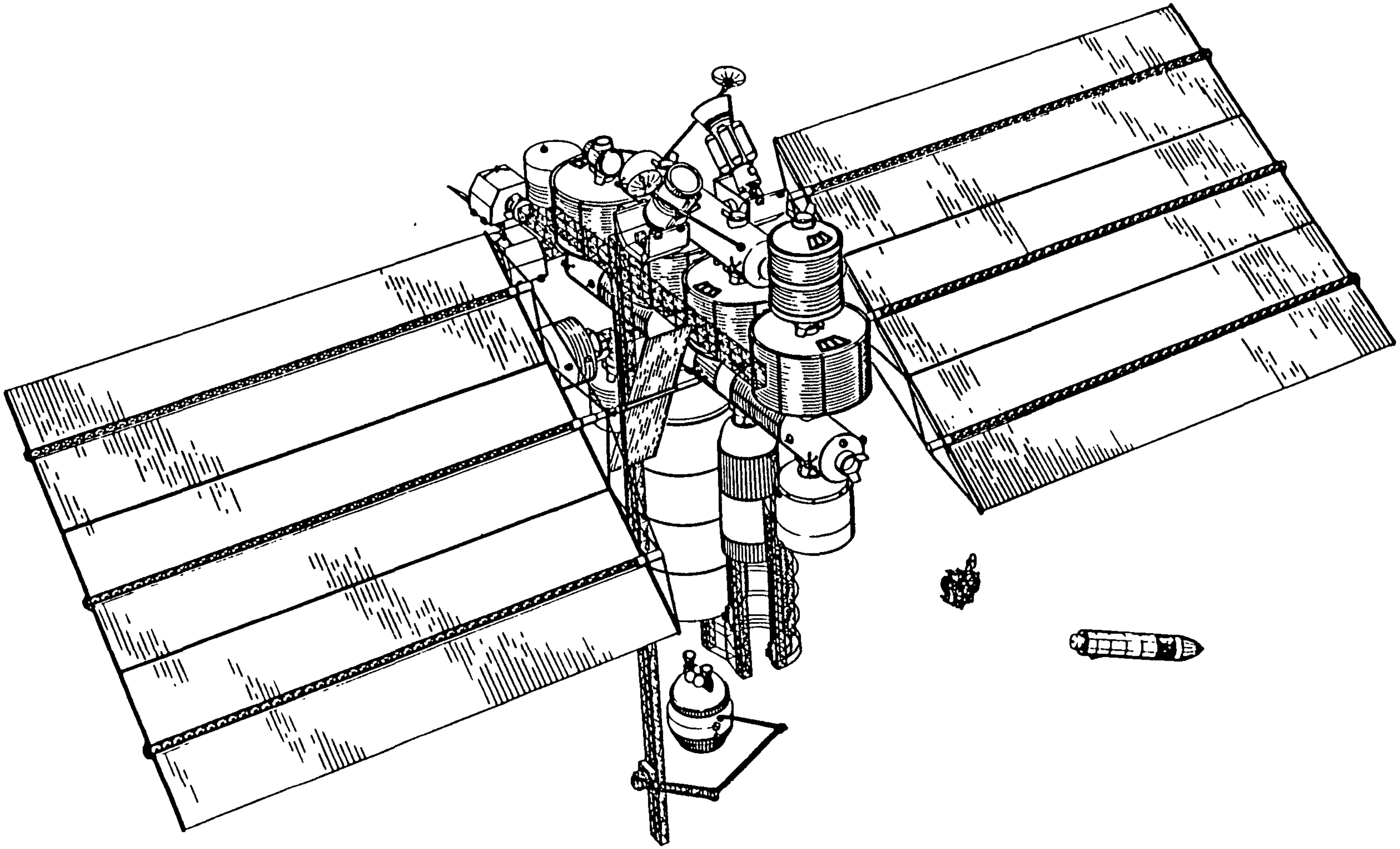


Figure 3.2.2-2 Modular Aft Cargo Carrier Space Station

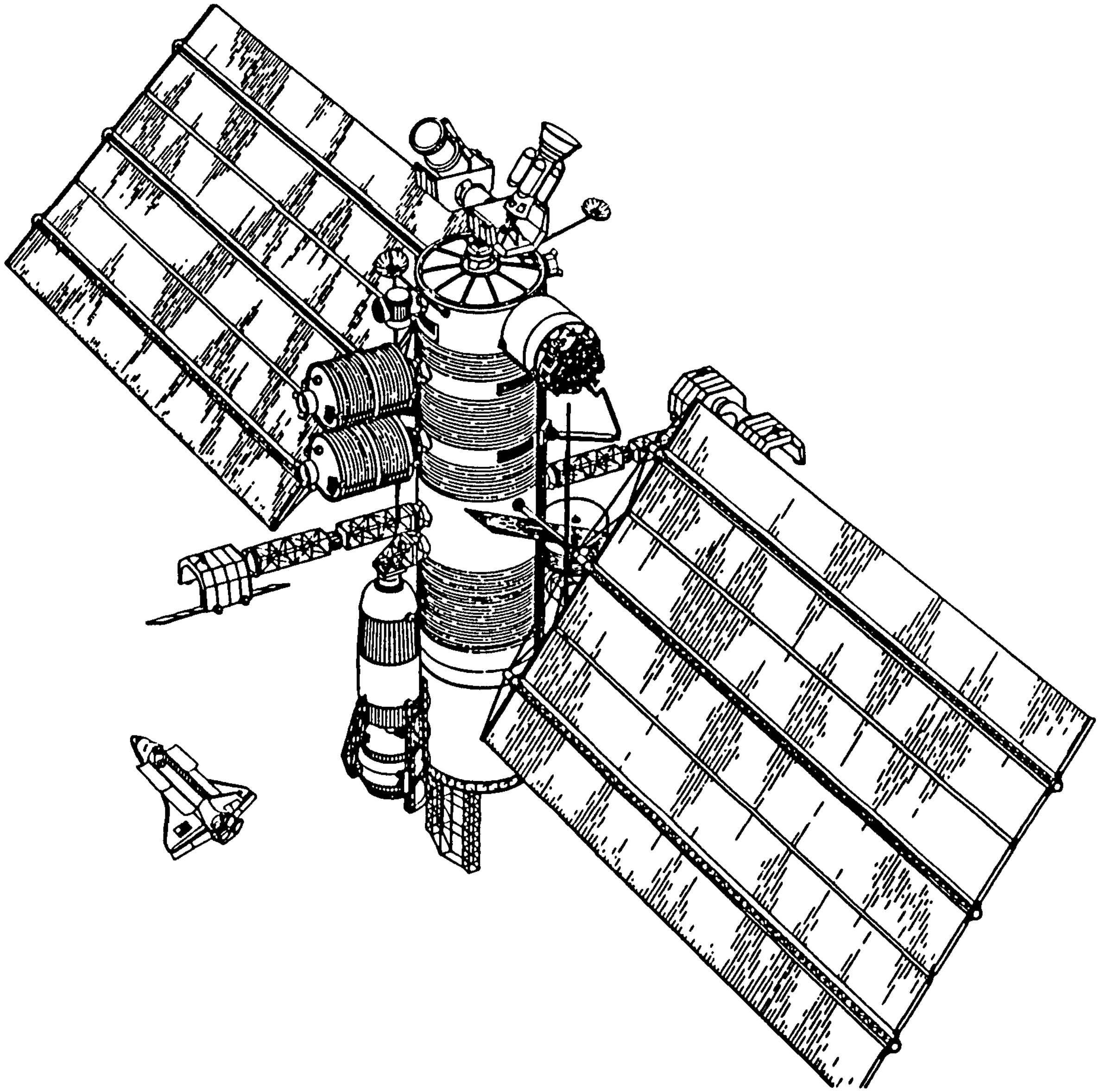


Figure 3.2.2-3 Shuttle Derived Vehicle Space Station

3.3 PROGRAM GROUNDRULES AND ASSUMPTIONS

The general program groundrules and assumptions included in the statement of work were followed in the course of this study except as modified or expanded below.

a. The permanent facilities defined during this study will be Shuttle launched and Shuttle tended, as required. The Space Shuttle User's Handbook was used to provide the associated guidelines.

   (We have expanded this to include not only consideration of the Shuttle orbiter as a launch vehicle but also an External Tank Aft Cargo Carrier (ACC) and a Shuttle Derived Vehicle (SDV) as potential launch vehicles.)

b. Potential missions of interest included domestic and foreign science, applications and commercial users as well as US national security and space operations missions.

c. The time period of interest was the later 1980's through the year 2000.

d. Missions identified and included in the study results have identified users, and include the specific source of user input. The validity of the missions and requirements for the space station developed under this study was determined in part by the traceability of user data.

e. Although the study primarily considered the requirements for a permanent manned space station in low earth orbit, requirements for the full range of potential future support systems were established.

f. The Tracking and Data Relay Satellite System (TDRSS) will be the primary space-to-ground RF communications interface for space station operations. The TDRSS User's Guide was used to define the space station interfaces.

g. Development of space station attributes and architectural options considered the accommodation of all feasible missions with a single space station in the 1990 time frame. The evolutionary growth of the system could require consideration of multiple space facilities.

h. DOD Task Assignment - We considered space station interaction with the total DOD space infrastructure envisioned to be in use in the later 1980s through the year 2000. A mission model delineating the military space missions under development and under consideration for the time period specified above was provided by DOD.

The following groundrules and assumptions were provided at the Contractor Orientation Briefing:

a. FY84 $ in millions

b. Cost submitted at the subsystem level (e.g., avionics, system engineering) if it is estimated at that level; otherwise, only to level estimated.

c. Schedules submitted at the module level (e.g., habitation module), with major subsystem milestones presented

d. Milestones submitted in terms of FY1, FY2 (instead of 1985, 1986).

e. DRD MF003M formats and SSCAG standard WBS suggested.

The following groundrules and assumptions were developed in the course of preparing the costs, economic benefits and program schedules for this study.

1. A protoflight approach for flight hardware was assumed. No module level qual test article will be built.

2. The subsystem design life will be 10 years.

3. On-orbit repair or refurbishment of subsystems will be accomplished as required to extend the design life of the system.

4. Hardware not space qualified will be qualified at the subsystem level.

5. Spares will be provided at the component or space replaceable level.

6. High reliability space qualified parts will be used.

7. A factory to pad concept of hardware flow was assumed.

8. No station level end-to-end systems test will be required.

9. A single set of ground support equipment was assumed.

10. Reusable on-orbit maintained orbit transfer vehicles and teleoperator maneuvering systems will be available for use in space station operations. Development costs were considered in NASA budgets for affordability analysis but unit costs only are included in the space station cost estimate.

11. Production and test facilities were assumed to exist.

Table 3.3-1 Data Form H, Summary of Hardware Quantities, lists the quantities of hardware by major element. Some items such as solar arrays do not appear in the cost section because they were included in a module cost estimate. The solar array costs, for example, are included in the energy section cost estimate.

Table 3.3-1 Data Form H Summary of Hardware Quantities

a. Subsystem	b. No of *Development* Units	c. No of *Qual* Units	d. No of *Major Test* Units	e. Refur-*bishment* Units	f. No of *Production* Units	g. *Initial* Spares	h. *Operational* Spares	i. *Total* Units
Energy Section	1	0	2*	0.25	1	0.3		4.55
Habitat Module	1	0	2*	0.25	2	0.45		5.7
Logistics Module	1	0	2*	0.25	1	0.3		4.55
Solar Array	1	0	2*	0.25	1	0.3		4.55
Materials Processing Lab	1	0	2*	0.25	-	0.15		3.4
Payload Pallets	0	0	0	0	5	0.3		5.3
Construction Equip	1	0	2*	0.25	-	0.15		3.4
Cryo Storage & Transfer	1	0	-	0.25	-	0.15		1.4
Hangar	1	0	2*	0.25	-	0.15		3.4
Docking Tunnel	1	0	2*	0.25	-	0.15		3.4
Platforms	1	0	1**	0.25	6	0.9		9.15
Life Sciences Research Lab	1	0	2*	0.25	-	0.15		3.4
Teleoperator Maneuvering System (TMS)	0	0	0	0	2	0.3		2.3
Man Maneuvering Unit (MMU)	0	0	0	0	2	0.3		2.3
Orbit Transfer Vehicle (OTV)	0	0	0	0	2	0.3		2.3
Shuttle Derived Vehicle Concept								
SDV Module	1	0	2***	0.25	0	0.15		1.4

* One-G Mockup & Neutral Bouyancy Article

** One-G Mockup

*** Sections of the SDV module would require One-G Mockups and Neutral Bouyancy Articles

THIS PAGE INTENTIONALLY LEFT BLANK

4.0 AFFORDABILITY

4.1 APPROACH

An important part of our programmatics task was the affordability analysis. Consideration of affordability is important in two major areas; the science missions that will occur in the 1990's and the development and building of the space station.

In order to develop realistic user requirements for a space station it was necessary to establish a realistic affordable mission model. We started with the Composite Mission Model presented at the mid-term review as the comprehensive set of missions that the user community desired to conduct given that no budget constraints exist. We then determined the subset of those missions that were affordable within the limits of projected NASA budget allocations.

The approach we used to determine an affordable mission model was to first review NASA budget history to determine the trend of both total budget and budget allocations to the continuing programs and new starts. We found that a ten year average NASA budget in fiscal year 1984 dollars was $7.2 billion. We set $7.2 billion as a target budget ceiling for our affordability analyses.

Our next step was to determine the budget allocations by major programs and extrapolate these into the future using the groundrules and assumptions presented at the end of this section. We used an early ROM estimate of a space station program cost as a strawman budget allocation and then refined it as our space station cost estimates matured. In this manner we determined the budget allocations by mission category out to the year 2000. These budget allocations are shown in Figure 4.1-1 NASA Budget Projection.

The following groundrules and assumptions were used in performing this affordability analysis:

- Budget projections are constant FY 1984 dollars,
- NASA Budget will remain constant at $7.2 billion.
- The following budget items will remain constant
  - o Research and program management
  - o Construction or facilities
  - o Space tracking and data systems
  - o Aeronautics and space R&T
- STS DDT&E funding will decline to $200M in FY 85 and remain constant at $200M to provide upgrades and improvements.
- STS production funding will decline to $250M in FY 87 and remain constant to provide for spare and replacement parts.

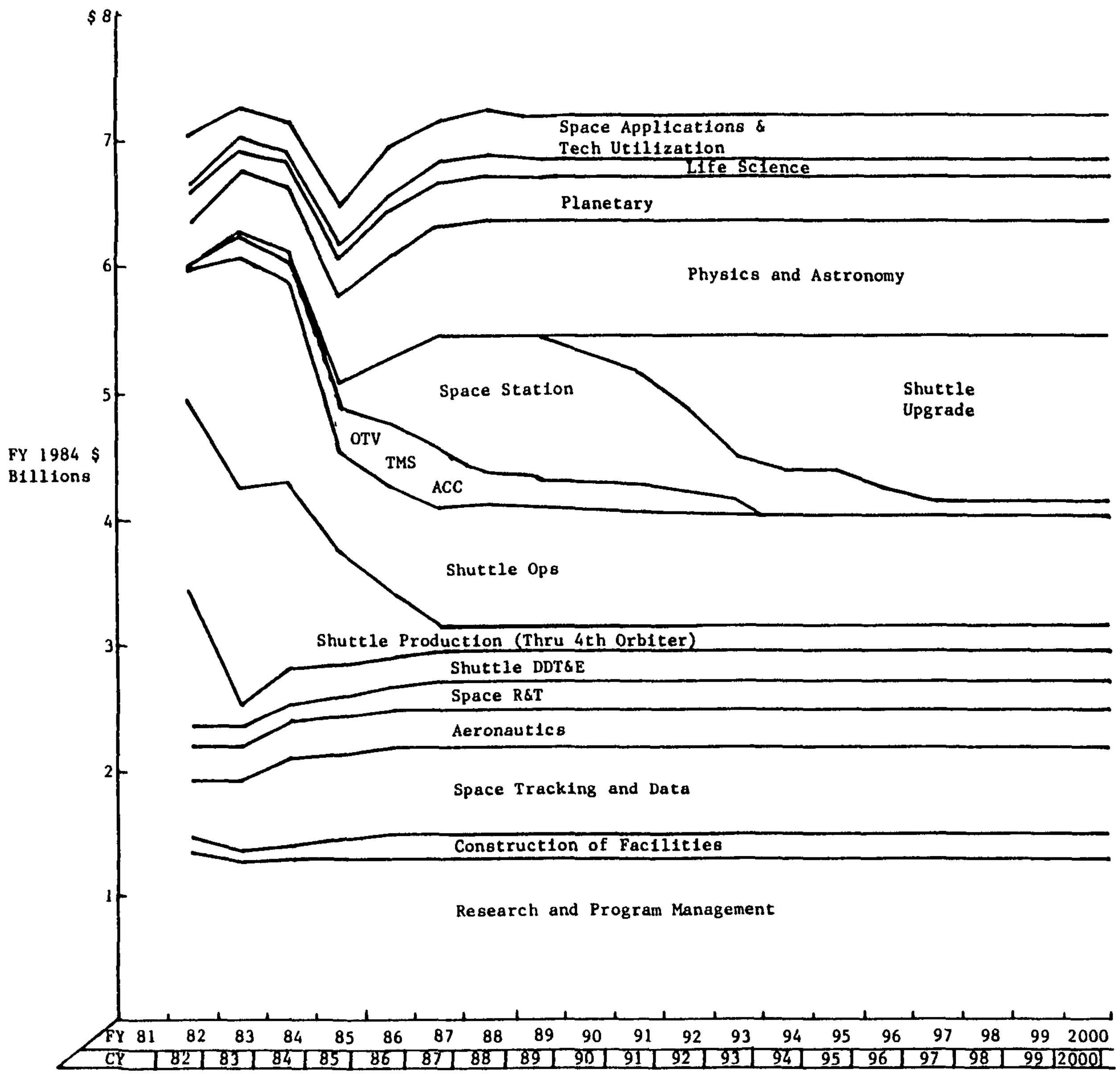


Figure 4.1-1 NASA Budget Projection

- Procurement of a potential fifth orbiter would not be funded by NASA.

- Shuttle operations funding by NASA will be at 80% of cost until 1985 and 36% of cost thereafter.

4.2 MISSION AFFORDABILITY

The objective of the mission affordability task was to refine the Composite Mission Model to that subset of missions that were affordable within the limits of the budget allocations by mission category. The first step in accomplishing this objective was to estimate the rough order of magnitude (ROM) cost of each mission in the mission model. This was done parametrically and by analogy to past missions. Where available we used published reports that presented budgetary estimates for missions. One such report was Astronomy and Astrophysics for the 1980's, Volume 1: Report of the Astronomy Survey Committee. The next step was to establish a priority ranking of the missions which considered among other things scientific benefit and time criticality such as a rendezvous mission.

In the process of matching mission costs to the budget allocation we made the simplifying assumption that the program costs would be equally distributed over the program development span. We judged that the buildup and phase out portions of a typical bell shaped program cost time distribution curve would equal out from one mission to another and thus would not significantly affect the outcome of the analysis.

By fitting the mission cost curves under the budget limit for each particular mission category we determined an affordable launch date by mission. This mission IOC date then became a part of the Space Station Mission Model which was the basis for determining a set of realistic user mission requirements for the space station. Figures 4.2-1 through 4.2-4 show the results of this process.

4.3 SPACE STATION AFFORDABILITY

The space station affordability analysis was conducted in a similar manner to the mission affordability analysis. As mentioned previously we made an initial strawman space station budget allocation based on our initial ROM cost estimates for a space station. As our configurations matured we were able to refine our cost estimates and use higher confidence annual funding requirements for the affordability analysis.

The entire affordability analysis task was one of balancing an affordable mission requirements model with a space station cost of capability. Many iterations of matching costs to budgets were required before we arrived at what we feel is a program that meets user demand at an affordable fiscal year cost.

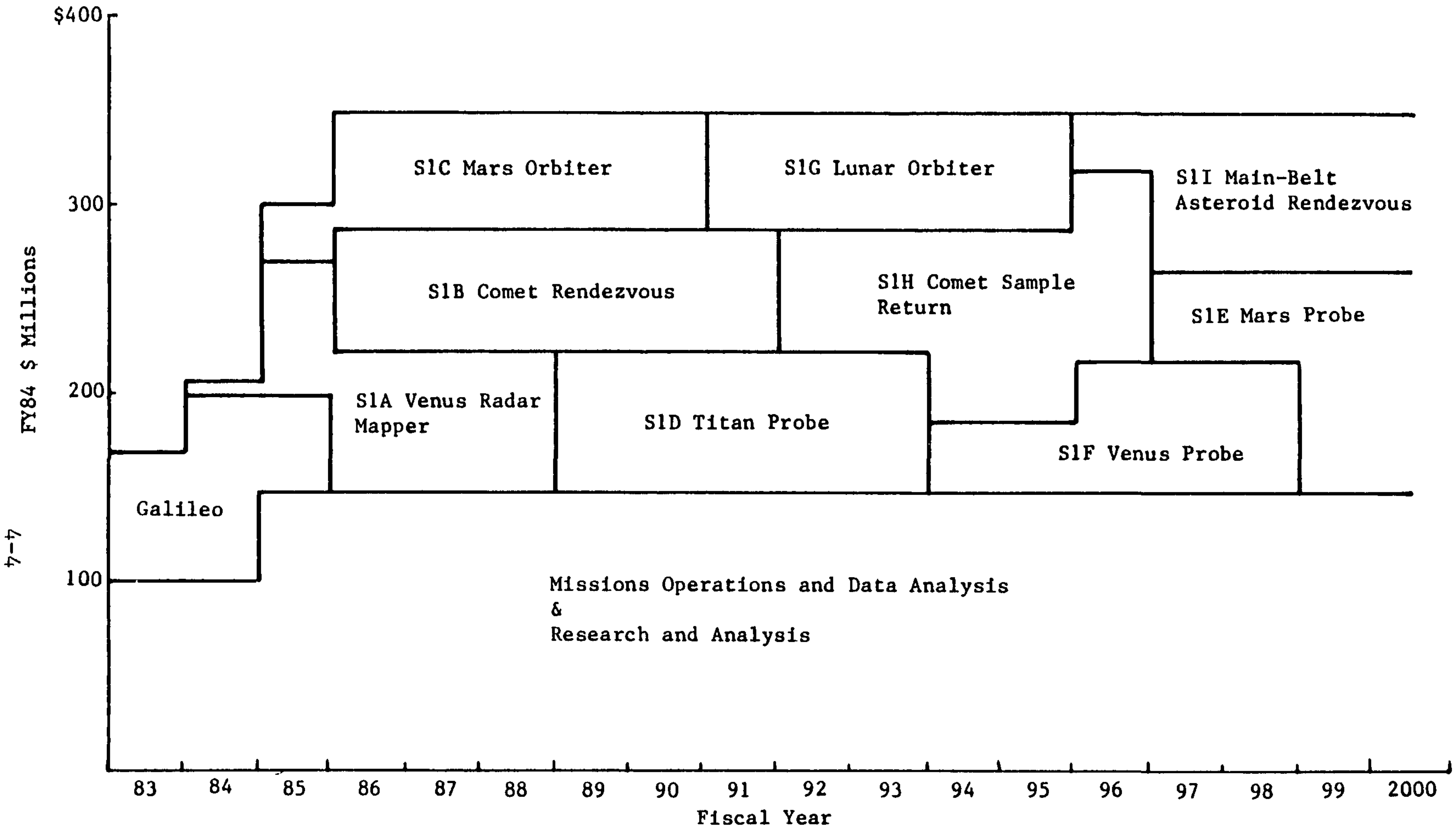


Figure 4.2-1 Planetary Missions Affordability Analysis

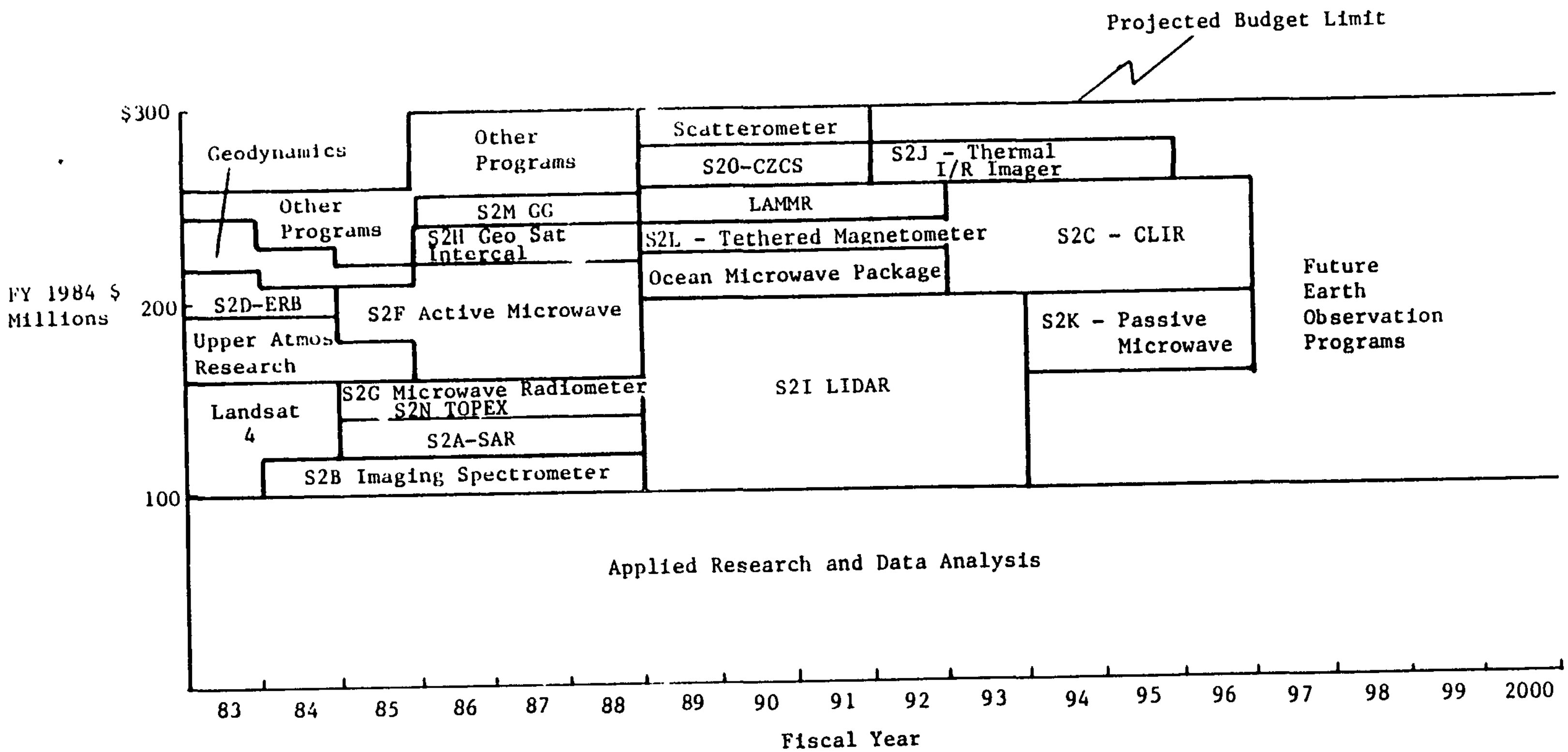


Figure 4.2-2 Earth Observation Affordability Analysis

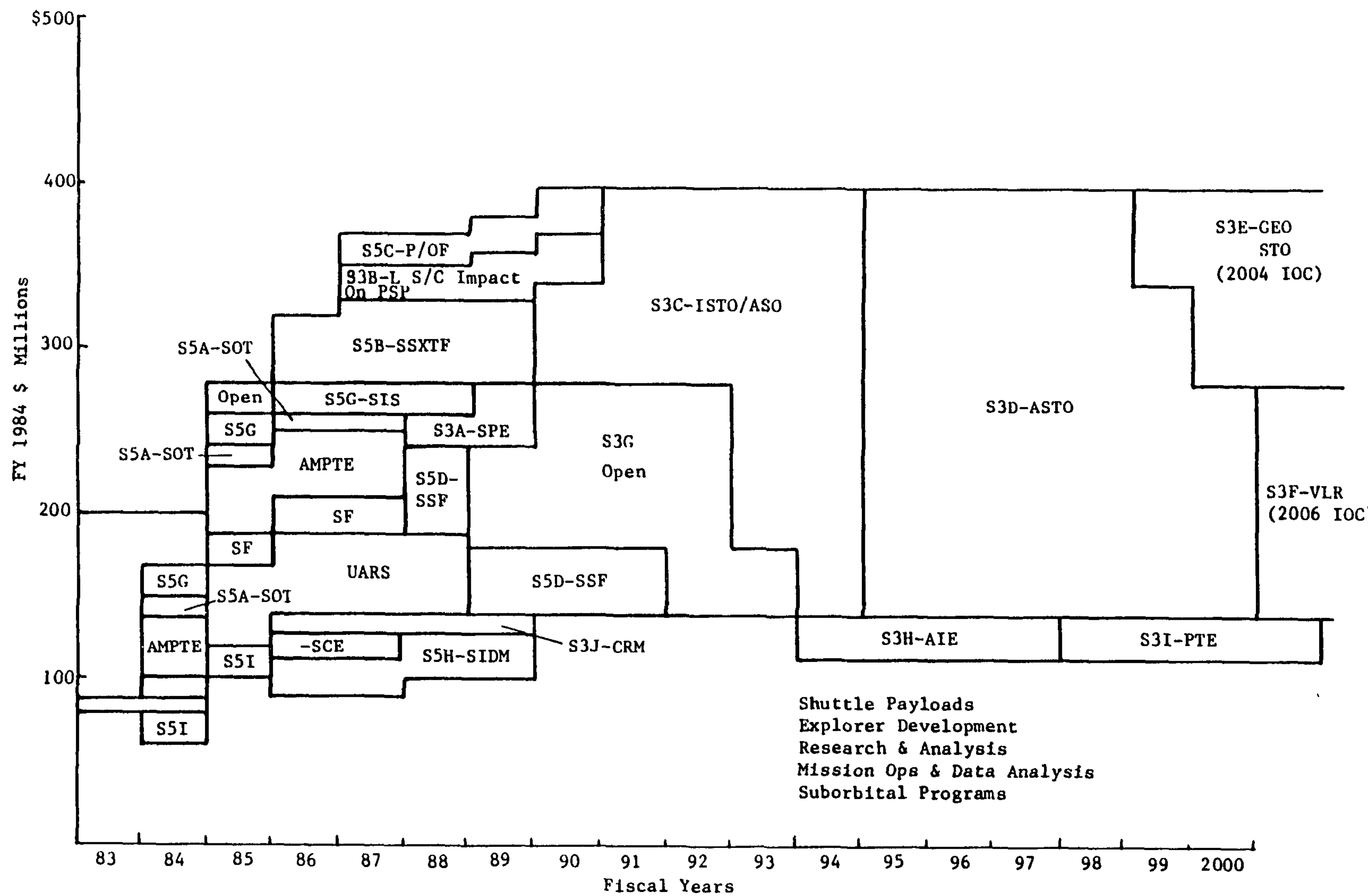


Figure 4.2-3 Space and Solar Physics Missions Affordability Analysis

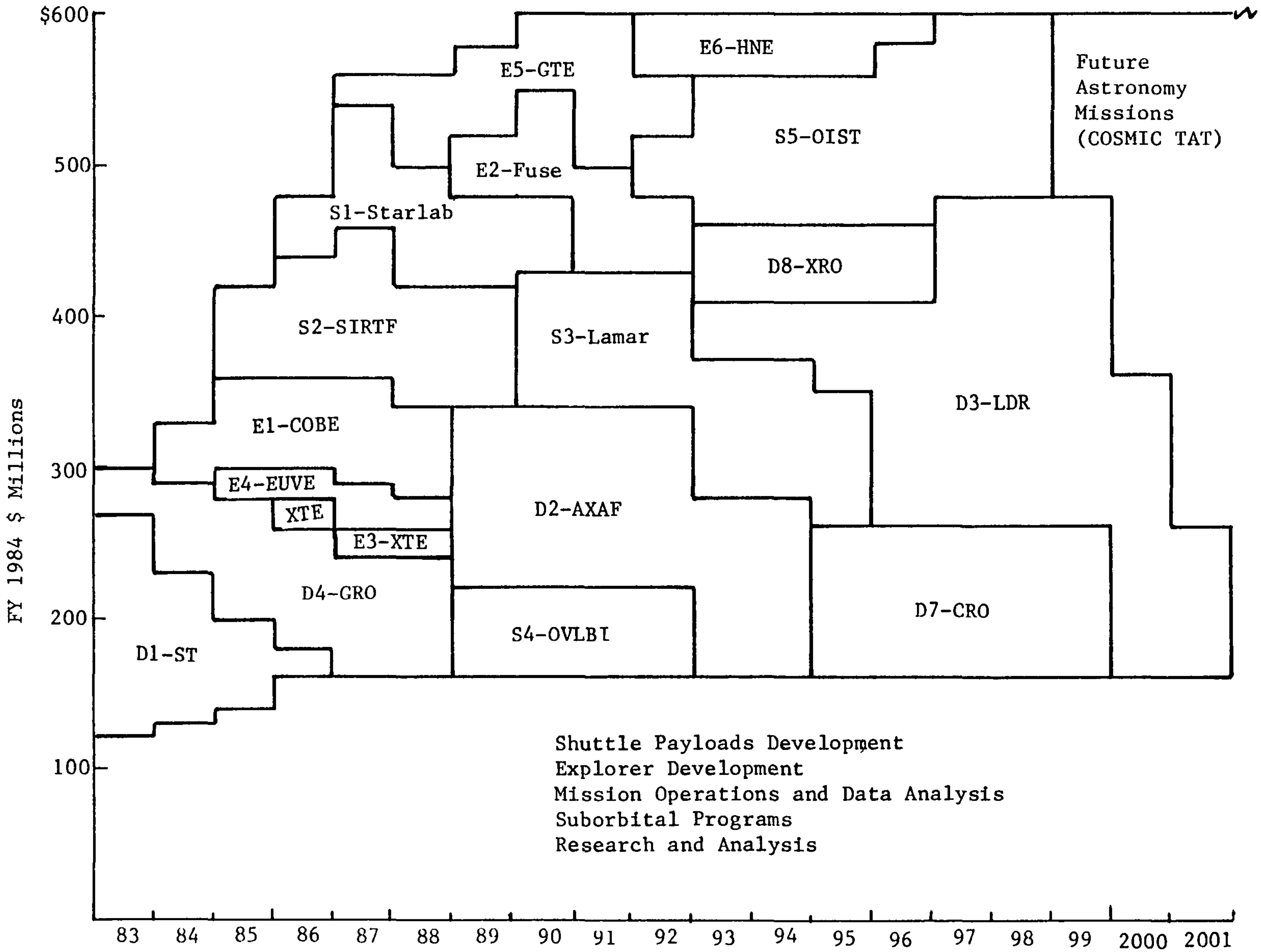


Figure 4.2-4 Astronomy Missions Affordability Analysis

A major concern of the Shuttle Derived Vehicle (SDV) space station concept was high early funding that might be required. The SDV space station concept does require a higher level of front end funding if the IOC date of 1991 is held. However if the IOC date is relaxed to 1992 the fiscal year peak funding required is less than that required for a modular concept of a space station.

To determine the affordability of an SDV configuration space station we replaced the modular concept funding with an SDV concept funding assuming a 1992 IOC. We then inserted the SDV program funding that would be required to develop the Class I SDV concept with ballistic propulsion/avionics module. With an assumption that the science mission budget remains constant at the early 1980's level of about a billion 1984 dollars, the peak NASA budget required in building a SDV space station occurs in FY 1989 and is about $7.5 billion.

If the science missions budget is allowed to grow to $1.85 billion as in the modular concept analysis the peak funding of about $8.0 billion in FY 84 dollars occurs in FY 1989.

Under either funding assumption the budget demands are reasonable and exceed a targeted $7.2 billion budget only in two years in the first case presented and five years in the second scenario.

5.0 ECONOMIC BENEFITS

A permanent manned Space Station in low Earth orbit will provide cost-effective space operations as well as capabilities to support DOD missions and new space industries. Our studies have identified the following principal economic benefits:

1) A manned Space Station will enable the conduct of space missions and their respective operations with fewer Shuttle flights. Satellite servicing, for example, can be completed without scheduling a dedicated Shuttle flight for each servicing mission. Service equipment can be based at the Space Station instead of being transported to and from orbit for each use. In addition, automated systems for servicing of spacecraft in geosynchronous orbit will provide timely response in the event of unexpected spacecraft failures.

2) The benefits derived from LEO and GEO delivery missions are potentially very significant. The combination of using Shuttle and Space Station will allow increased efficiency in manifesting compared to using Shuttle alone. This improved manifesting will reduce the number of STS flights to deliver LEO and GEO payloads.

3) A Space Station will provide a cost effective basing mode for user payloads by providing utilities such as structure, attitude control, power and thermal control. This basing benefit results from either attachment to the manned Space Station or one of the platforms that are a part of the Space Station architecture. These services would otherwise be provided by free flyers that each user would have to design and build independently.

A major objective of the economic benefits analysis was to aid in the selection of program options and Space Station architectures. The benefit to cost ratios of each program option were compared and as a result we concluded that a single manned Space Station had a better benefit to cost ratio than multiple stations.

The next step in our selection process was to determine the most cost effective orbital inclination to locate the manned Space Station. Space Station mission analysis studies identified inclinations of 28.5°, 57° and 70° as the most promising inclinations (reference Volume 3, Section 6.0). The optimal inclination of 28.5° was selected because it had the highest benefit/cost ratio. Economic benefits from delivery, servicing, basing, assembly and operations were determined by comparing performance of the missions with Shuttle alone and with Space Station.

5.1 ECONOMIC BENEFITS SUMMARY

This section presents the basis for our economic benefits analysis and a summary of the Space Station economic benefits. We have defined a Space Station economic benefit as an activity attributable to a proposed capability increment that adds value because this activity can be completed in a less costly manner using a Space Station than by dedicated STS flights. All economic benefits and costs are in 1984 $'s. We have used $110 million per STS flight from ELS (based on 24 flights per year) and $150 million per STS flight from WLS (based on 6 flights per year). The only exception to the above cost per STS flight is that all WLS flights to a high inclination station (above 57°) are costed at $120 million per STS flight (based on 12 flights per year from WLS).

A summary of the economic benefits by Space Station inclination is presented in Table 5.1-1 (Economic Benefits Summary) and is presented graphically in Figure 5.1-1 (Economic Benefits by Inclination). For example, the economic benefits of GEO delivery from a 28.5° station results in "value added" of $6400 million. This indicates that if dedicated STS flights were used to make all GEO deliveries in our Affordable Mission Model it would cost $6400 million more than to make these deliveries from a 28.5° Inclination Space Station. Figures 5.1-2 (Cumulative Economic Benefits - Modular Space Station 28.5) and 5.1-3 (Cumulative Economic Benefits - SDV Space Station 28.5) display graphically the cumulative economic benefits. The following paragraphs discuss the quantification of the economic benefits.

GEO Delivery - GEO delivery from a 28.5° Inclination Space Station results in cost avoidance of $6400 million during the period of time from FY 1992 thru the year 2000 because 58 fewer STS flights are needed to deliver all the GEO payloads in our Affordable Mission Model as is shown in Table 5.1-2 (Delivery and Servicing Economic Benefits). Cost avoidance of $6400 million was calculated by multiplying the 58 STS flights times $110 million per STS flight (58 x $110 million = $6400 million). Our performance analysis was conducted for missions from 1989 to 2000. We have concluded that we could not provide GEO delivery capability until FY 1992. Therefore, we have taken a ratio of missions for ten years versus the twelve years our performance analysis covers. Table 5.1-3 (GEO Delivery Launch Requirements Analysis) presents a summary of our analysis to determine the number of delta STS flights. This table indicates that for a 28.5° Inclination Space Station there are 214 GEO delivery flights from 1989-2000 that can be delivered more efficiently by a 28.5° Inclination Space Station than by STS dedicated flights. These 214 flights were divided into payload classes based on similar inclinations, altitudes, payload weights, etc. Our parametric mission analysis determined the number of STS flights required to deliver all flights in each payload class using a 28.5° SS and STS dedicated flights. For example, we estimate that the 42 flights in payload class #2 will take 40.3 dedicated STS flights and 23.2 STS Space Station flights. This results in 17.1 (40.3-23.2 = 17.1) delta STS flights over the 12 year period. Since our estimate of benefits is

Table 5.1-1
Economic Benefits Summary (1984 $M)

	28.5°	57°	70°
GEO Delivery	$ 6400	$2300	$-
Basing	3600	3600	3600
LEO Servicing	2600	1700	1000
LEO Delivery	2200	1900	-
GEO Servicing	400	100	-
	$15,200	$9600	$4600

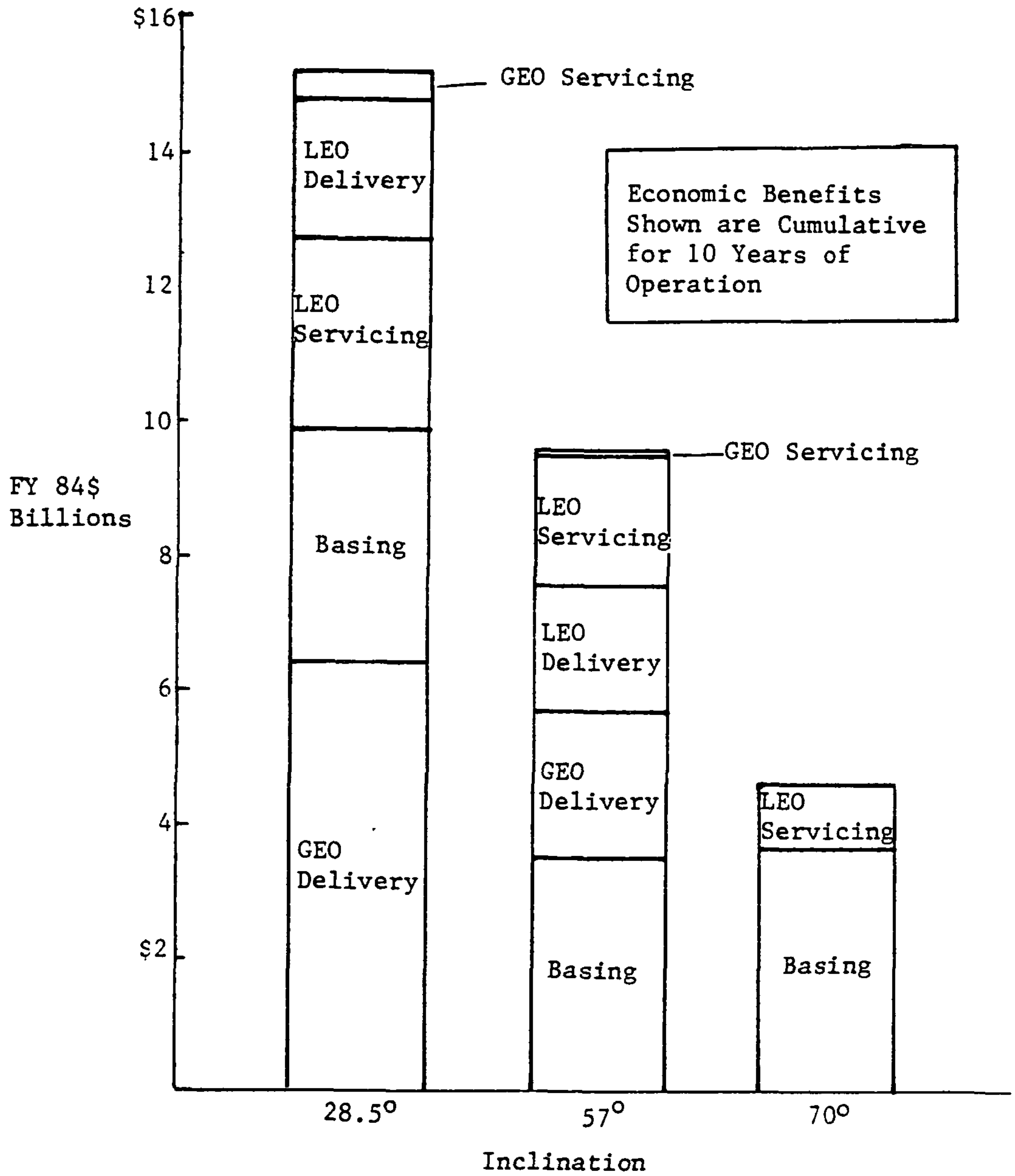


Figure 5.1-1 Economic Benefits by Inclination

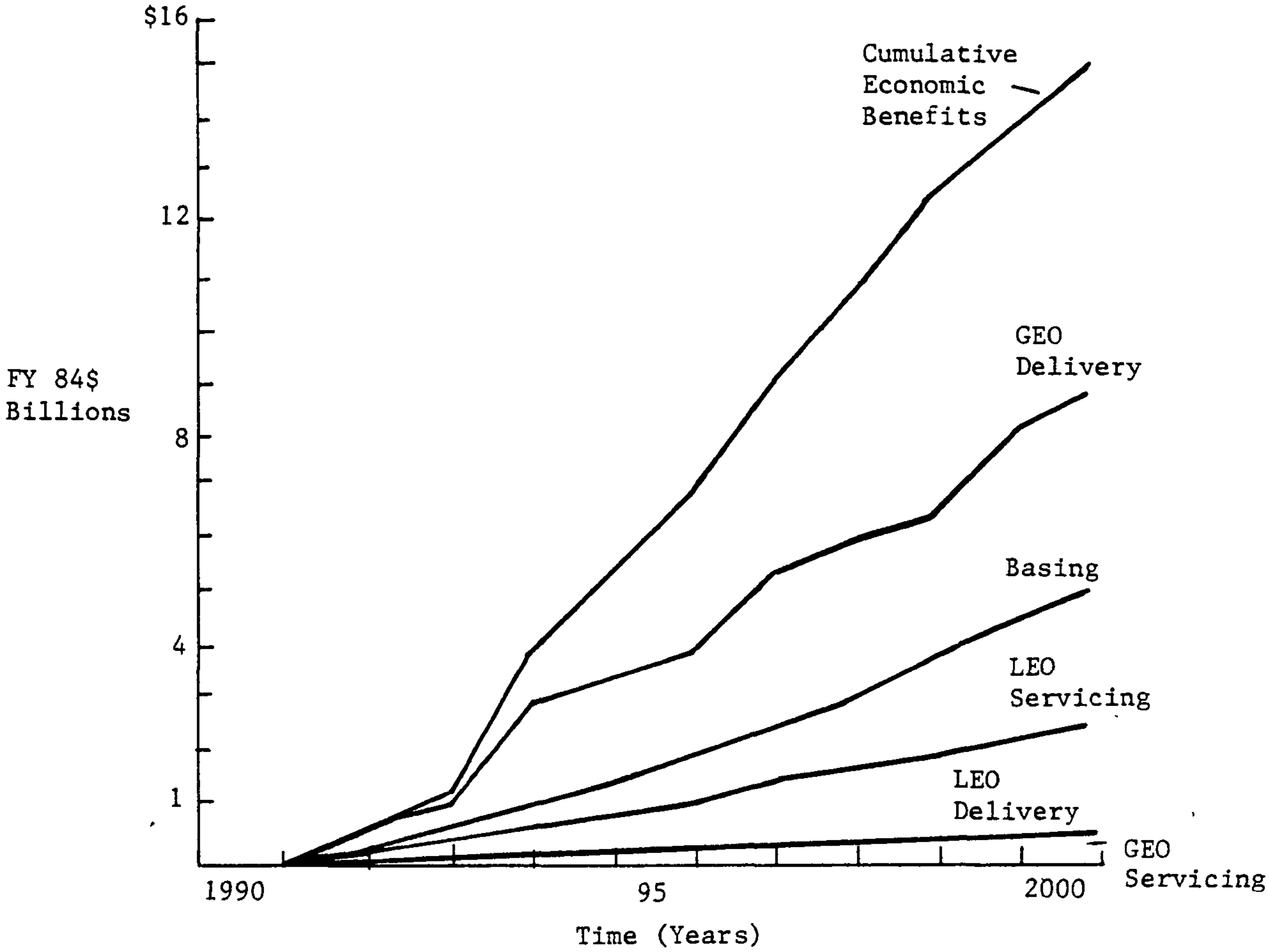


Figure 5.1-2 Cumulative Economic Benefits - Modular Space Station 28.5°

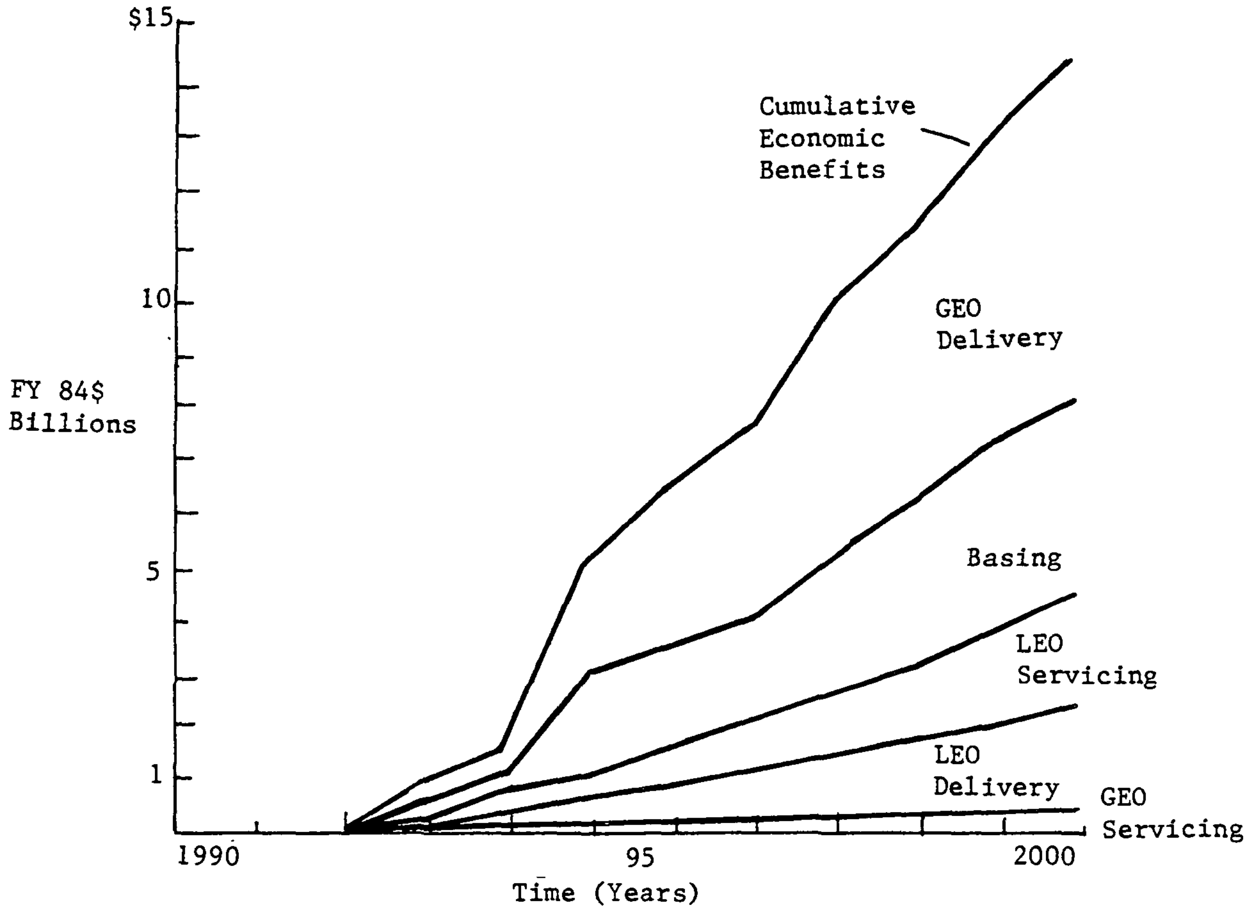


Figure 5.1-3 Cumulative Economic Benefits - SDV Space Station 28.5°

Table 5.1-2 Delivery and Servicing Economic Benefits

	'Δ' STS Flights			'Δ' STS Transportation Cost (84 $ M)		
	GEO	LEO	Total	GEO	LEO	Total
Delivery						
- 28.5° SS	58	20	78	$6400	$2200	$8600
- 57° SS	21	17	38	2300	1900	4200
- 70° SS	(No Advantage)	(No Advantage)	-	-	-	-
Servicing						
- 28.5° SS	4	24	28	400	2600	3000
- 57° SS	1	15	16	100	1700	1800
- 70° SS	(No Advantage)	8	8	-	1000	1000

Table 5.1-3 GEO Delivery Launch Requirements Analysis

Payload Class	Inclination	(1989-2000) No. of Flights	STS Dedicated Flights	STS Space Station Flights	Delta STS Flights-12 Yrs	Delta STS Flights-10 Yrs
28.5° Inclination SS						
2	0°	42	40.3	23.2	17.1	14.3
3	0°	37	27.8	15.5	12.3	10.3
4	0°	96	60.5	32.8	27.7	23.1
5	0°	29	17.1	9.1	8.0	6.7
6	28.5°	6	4.8	2.6	2.2	1.8
13	57°	4	4.1	2.4	1.7	1.4
		214	154.6	85.6	69.0	57.6
57° Inclination SS						
2	0°	42	40.3	34.8	5.5	4.6
3	0°	37	27.8	23.6	4.2	3.5
4	0°	96	60.5	50.8	9.7	8.1
5	0°	29	17.1	14.2	2.9	2.4
6	28.5°	6	4.8	3.8	1.0	0.8
13	57°	4	4.1	2.7	1.4	1.2
		214	154.6	129.9	24.7	20.6
70° Inclination SS						
5	0°	29	17.1	16.9	0.2	0.2
6	28.5°	6	4.8	4.6	0.2	0.2
13	57°	4	4.1	3.2	0.9	0.7
		39	26.0	24.7	1.3	1.1

over a ten-year period (1991-2000) we have reduced the delta STS flights from 17.1 to 14.3 by multiplying by 10/12 (17.1x10/12 = 14.3). The sum of all the delta STS flights results in approximately 58 less STS flights from a 28.5° Inclination Space Station versus STS dedicated flights. The efficiencies of a Space Station reduces the number of GEO delivery STS flights significantly because the ASE weight can be reduced and the OTV does not have to be transported to and from orbit for each use.

GEO delivery for a 57° Inclination Space Station results in 21 delta STS flights or cost avoidance of $2300 million. A 70° Inclination Space Station does not gain an advantage over dedicated STS for GEO delivery.

LEO Delivery - The economic benefits of LEO delivery were estimated using two separate methods. The first method was based on our parametric mission analysis studies which is similar to the method used for GEO delivery. Table 5.1-4 (LEO Delivery Launch Requirements Analysis) indicates that approximately 16 STS flights can be avoided in LEO delivery from a 28.5° Inclination Space Station. The second method is based on manifesting all LEO deliveries in the Affordable Mission Model for Fiscal 1995. Table 5.1-5 (Affordable Mission Model LEO Deliveries in 1995 for 28.5° Inclination SS) lists the missions to be manifested and the total stage weight in pounds of each mission for both STS dedicated and a 28.5° Inclination Space Station. Note that with a Space Station the ASE weight can be reduced significantly and that the OTV does not have to be transported to and from orbit for each use. Therefore, the total stage weight of the missions that go to a Space Station is significantly less than those using STS dedicated flights. In Table 5.1-6 (LEO STS Flight Manifesting in 1995 for a 28.5° Inclination SS) we have manifested the total stage weight of these missions (volume was not considered due to the lack of data) to determine the total number of STS flights for both STS dedicated and a 28.5° Inclination Space Station. The results indicate that two STS flights per year or 20 STS over ten years could be avoided with a 28.5° Inclination Space Station. In addition, the Space Station case allows additional capacity for resupply missions and/or topping off with propellant.

To calculate economic benefits for LEO delivery for the 28.5° Inclination Space Station we have used the 20 STS flights that were avoided for LEO delivery as is shown in Table 5.1-2 (Delivery and Servicing Economic Benefits). The 20 delta STS flights results in cost avoidance of $2200 million.

LEO delivery for a 57° Inclination Space Station results in 17 delta STS flights or cost avoidance of $1900 million. We found no advantage to LEO delivery for a 70° Inclination Space Station over dedicated STS flights.

Table 5.1-4 LEO Delivery Launch Requirements Analysis

Payload Class	Inclination	(1989-2000) No. of Flights	STS Dedicated Flights	STS Space Station Flights	Delta STS Flights-12 Yrs	Delta STS Flights-10 Yrs
28.5° Inclination SS						
6	28.5°	6	5.2	2.8	2.4	2.0
7	28.5°	3	1.5	0.8	0.7	0.6
8A	-	10	1.0	0.9	0.1	0.1
8B	-	14	8.5	6.7	1.8	1.5
9	$42-46^{\circ}$	7	3.5	3.0	0.5	0.4
10	55°	51	26.7	17.9	8.8	7.4
11	55°	12	11.4	9.7	1.7	1.4
13	57°	4	4.5	2.6	1.9	1.6
17	60°	5	3.6	2.5	1.1	0.9
		112	65.9	46.9	19.0	15.9
57° Inclination SS						
6	28.5°	6	5.3	4.1	1.2	1.0
9	45°	7	3.5	3.3	0.2	0.2
10	55°	51	26.7	18.3	8.4	7.0
11	55.5°	12	11.4	7.2	4.2	3.5
12A	56°	4	1.3	1.0	0.3	0.3
12B	56°	1	1.1	1.0	0.1	0.1
13	57°	4	4.5	2.9	1.6	1.3
14	57°	2	1.1	0.5	0.6	0.5
15	57°	4	1.1	0.7	0.4	0.3
16A	57°	1	1.0	0.8	0.2	0.2
16B	57°	2	5.2	4.9	0.3	0.2
17	60°	5	3.6	2.4	1.2	1.0
18	60°	1	2.5	1.3	1.2	1.0
19	65°	8	0.3	0.1	0.2	0.2
20	74°	3	1.9	1.5	0.4	0.3
		111	70.5	50.0	20.5	17.1
70° Inclination SS						
10	55°	51	20.7	24.2	(No Advantage)	(No Advantage)
11	$55-56^{\circ}$	12	9.7	10.3	(No Advantage)	(No Advantage)
14	57°	2	0.9	1.0	(No Advantage)	(No Advantage)
17	60°	5	2.6	3.3	(No Advantage)	(No Advantage)
18	60°	8	1.6	2.3	(No Advantage)	(No Advantage)
19	65°	1	0.2	0.3	(No Advantage)	(No Advantage)
20	74°	3	0.9	1.7	(No Advantage)	(No Advantage)
		82	36.6	43.1	(No Advantage)	(No Advantage)

Table 5.1-5 Affordable Mission Model LEO Deliveries in 1995 for 28.5° SS

	STS Dedicated					With Space Station			
	Payload Wt	Propellant Wt	OTV or TMS Wt	ASE Wt	Total Stage Wt	Payload Wt	Propellant Wt	ASE Wt	Total Stage Wt
Mission #1 (28.5°; 216 NM)	6.6K	0.4K	3.5K	-	10.5K	#1' 6.6K	0.4K	-	7.0K
Mission #2 (42°; 248 NM)	11.0	18.0	5.7	6.0	34.7	#2' 11.0	18.0	1.5	30.5
Mission #3 (55°; 10,900 NM)									
A	2.2	16.5	5.7	6.0	30.4	#3A' 2.2	19.2	0.5	21.9
B	2.2	16.5	5.7	6.0	30.4	#3B' 2.2	19.2	0.5	21.9
C	2.2	16.5	5.7	6.0	30.4	#3C' 2.2	19.2	0.5	21.9
D	2.2	16.5	5.7	6.0	30.4	#3D' 2.2	19.2	0.5	21.9

Table 5.1-6 LEO STS Flight Manifesting for 28.5° SS (Year - 1995)

	STS Dedicated Flights	STS Space Station Flights
STS Flt #1	#1 & # 3A (10.5K + 30.4 = 40.9K lbs)	#1' & 2' (7.0 + 30.5 = 37.5K lbs)
STS Flt #2	#2 (34.7K lbs)	#3A' & 3B' (21.9 + 21.9 = 43.8K lbs)
STS Flt #3	#3B (30.4K lbs)	#3C' & 3D' (21.9 + 21.9 = 43.8K lbs)
STS Flt #4	#3C (30.4K lbs)	
STS FLT #5	#3D (30.4K lbs)	
Total STS Flights	5	3
Delta STS Flights = 2 Per Year (10 Years) ($110 M Per Flight) = $2200 M		

GEO and LEO Servicing - GEO and LEO servicing from a 28.5° Inclination Space Station results in cost avoidance of $400 million and $2600 million, respectively. These amounts of cost avoidance are based on delta STS flights of 4 and 24 for GEO and LEO servicing as is presented in Table 5.1-2 (Delivery and Servicing Economic Benefits). Table 5.1-7 (Servicing Launch Requirements Analysis) presents our estimates of the number of STS flights for GEO and LEO service missions for both dedicated STS and Space Station scenarios. The 16 GEO servicing missions for a 28.5° Inclination Space Station were estimated at one STS flight each for STS dedicated and .75 flights each for the Space Station case. Mission analysis studies determined that 57° and 70° Inclination Space Station's are 21% and 38% less efficient transportation wise than a 28.5° Inclination Space Station. Thus, since we estimated 12 STS flights for a 28.5° Inclination Space Station, a 57° Inclination Space Station would take 15 STS flights (12 x 1.21 = 15).

The 210 LEO servicing missions were also estimated parametrically based on mission analysis studies. Our estimate of 43 STS flights for a 28.5° Inclination Space Station and was increased by 21% and 38% for the 57° and 70° Inclination Space Station, respectively.

Basing - The economic benefits of providing utilities (power, thermal control, attitude control, etc.) to the missions based at the Space Station and on Space Station platforms has been quantified by estimating the cost if each of the missions were on individual spacecraft busses. Our estimate of the cost of an individual spacecraft bus is based on applying cost estimating relationships (cer's) from the Air Force Space Division's Unmanned Spacecraft Cost Model (June 1981) to a generic spacecraft bus. Table 5.1-8 (Spacecraft Bus Cost) identifies the subsystem weights used and the resulting cost estimates. This estimate indicates a first unit cost of $185 million and subsequent units at $85 million each. Table 5.1-9 (Economic Benefits of Space Station Basing) presents our estimate of the cost avoided resulting from Space Station basing. Note that the cost of a spacecraft bus for each mission is $85 million, except for the Space and Solar Physics facility class which is estimated at $300 million because of its similiarity to a platform. Thus, our estimate of cost avoidance from Space Station basing is $3710 million.

In summary, the economic benefits presented in Figure 5.1-1 (Economic Benefits by Inclination) clearly indicate that a 28.5°, 57° or 70° Inclination Space Station would be more cost effective than the combination of dedicated STS flights for delivery and servicing and free flyers for basing of missions. It is obvious from this table that the 28.5° Inclination Space Station will generate significantly larger economic benefits than both the 57° and 70° Inclination Space Station.

Table 5.1-7 Servicing Launch Requirements Analysis

	Altitude	Servicing Missions (1991-2000)	STS Dedicated Flights	STS Flights for SS Launches	Delta STS Flights
28.5° Inclination SS	GEO LEO	16 210 226	16 67 83	12 43 55	4 24 28
57° Inclination SS	GEO LEO	16 210 226	16 67 83	15 52 67	1 15 16
70° Inclination SS	GEO LEO	16 210 226	16 67 83	16 59 75	(No Advantage) 8 8

Table 5.1-8 Spacecraft Bus Cost

Subsystem	Subsystem Weight (lb)	1984 $ Millions	
		N/R Cost	Unit Cost
Structure/Thermal	980	$ 18.8	$ 3.3
Comm/TT&C	300	26.3	12.3
AC&DS	360	18.7	5.3
EPS	2125	15.0	7.5
Propulsion	225	4.5	3.4
Subtotal		$ 83.3	$31.8
Software		10.0	3.0
		93.3	34.8
Program Level Costs (45%)		42.0	15.7
		$135	$50

First Unit Cost = $185 M

Subsequent Units

- N/R @ 25% of 1st Unit 135 x .25 = $35
- Recurring @ 50

$85

Table 5.1-9 Economic Benefits of Space Station Basing

	FY84 $ Millions			
	Qty		Cost of Individual S/C Bus	Cost Avoidance
Missions Based at Space Station				
- Space Physics	1	X	$ 85	$ 85
- Materials Processing	4	X	$ 85	340
Missions Based at Platforms				
- Astronomy	4	X	$ 85	340
- Space & Solar Physics	8	X	$ 85	680
(Facility Class)	2	X	$300	600
- Earth Observation	6	X	$ 85	510
- Materials Processing	12	X	$ 85	1020
Spacecraft Bus N/R Cost				135
				$3710

5.2 BENEFITS VS COST BY CAPABILITY INCREMENT

The economic benefits derived from the various capability increments become more meaningful when compared to the marginal cost of each capability increment. Figure 5.2-1 (Marginal Costs and Economic Benefits by Capability Increment) presents the marginal cost and economic benefits of each capability increment. The marginal cost of each capability increment is defined as the additional cost to add a capability increment to the basic Space Station. The marginal cost of adding the GEO delivery capability includes a portion of the cost of adding a habitat and energy module, hangar, cryo storage tank, Orbiter tankage, platforms, pallets, OTV, TMS, servicer and operations cost to accomplish GEO delivery. The proportional cost of this hardware that is allocated to GEO delvery is based on the percent of total usage for GEO delivery. For example, GEO delivery was allocated $57 million of the $100 million procurement cost of an OTV because 57% of the total OTV flights are for GEO delivery.

In each case the marginal cost spent to add a capability increment results in economic benefits of at least two times the marginal cost. The most beneficial capability increment for each dollar of marginal cost spent was for GEO delivery which resulted in over $5 of benefits for each $1 spent.

Figure 5.2-2 (Cost/Benefit Breakeven Analysis-Modular Space Station 28.5^{o}) presents the cost/benefit breakeven analysis for the Modular Space Station. Note that the breakeven point occurs in 1998 at about $11.5 billion. By the year 2000 the cumulative economic benefits are almost $3 billion larger than the cumulative cost for the Modular Space Station.

The cost/benefit breakeven analysis for the SDV Space Station is presented in Figure 5.2-3 (Cost/Benefit Breakeven Analysis-SDV Space Station 28.5^{o}). The breakeven point occurs in 1998 at approximately $10 billion. The delta difference between cumulative economic benefits and cumulative cost in the year 2000 is over $3 billion.

5.3 EFFECT OF SCHEDULE VARIATION ON BENEFITS AND COST

The effect of schedule variation on benefits is shown in Figure 5.2-3 (Cost/Benefit Breakeven Analysis-SDV Space Station 28.5^{o}) when compared to Figure 5.2-2 (Cost/Benefit Breakeven Analysis-Modular Space Station 28.5^{o}). To hold the fiscal funding requirement for the SDV Space Station to about 20% of the NASA total budget required us to slip its IOC date from 1991 to 1992. The effect on benefits was to delay accumulation of the benefits by one year but does not have a significant affect other than the delay.

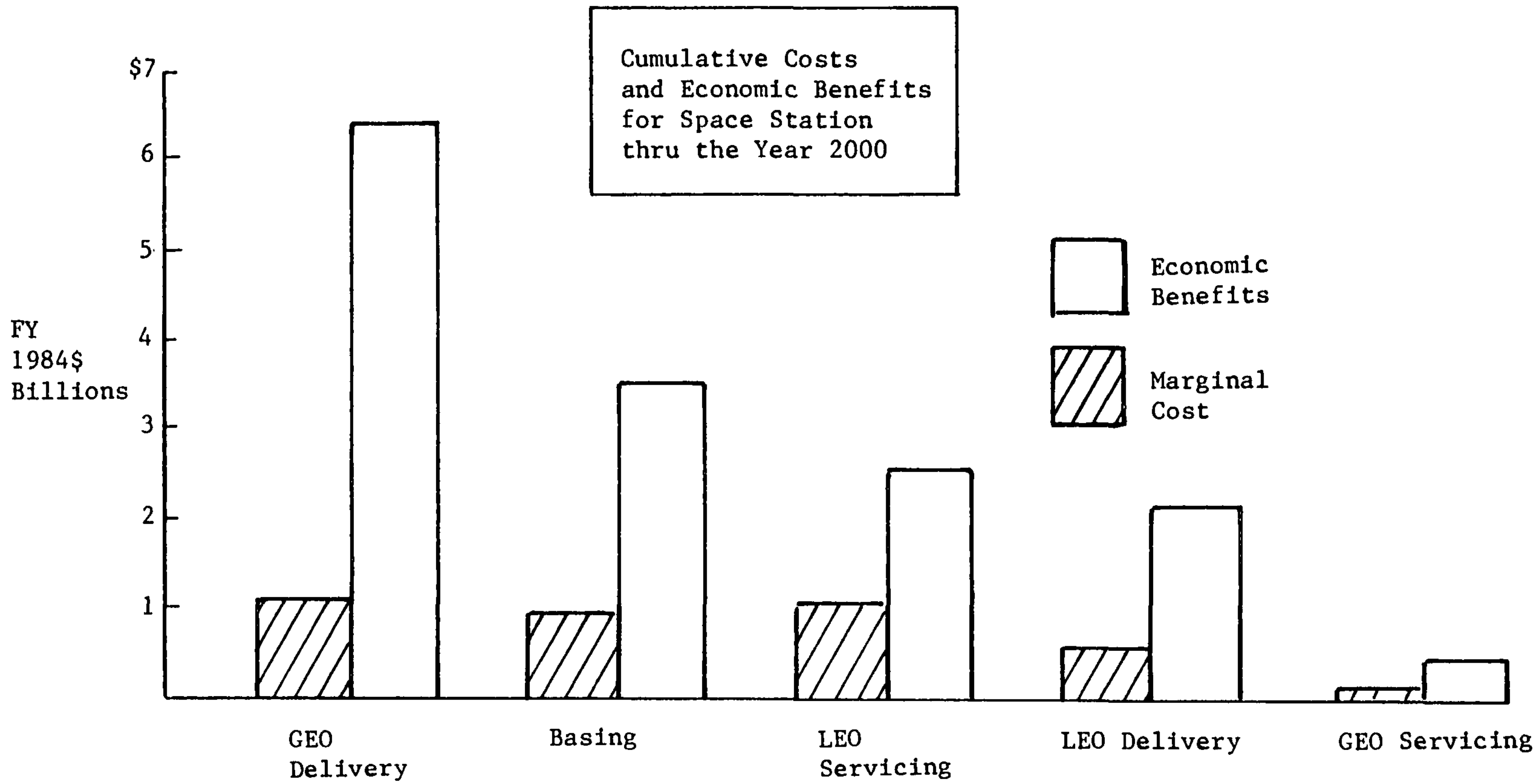


Figure 5.2-1 Marginal Costs and Economic Benefits by Capability Increment

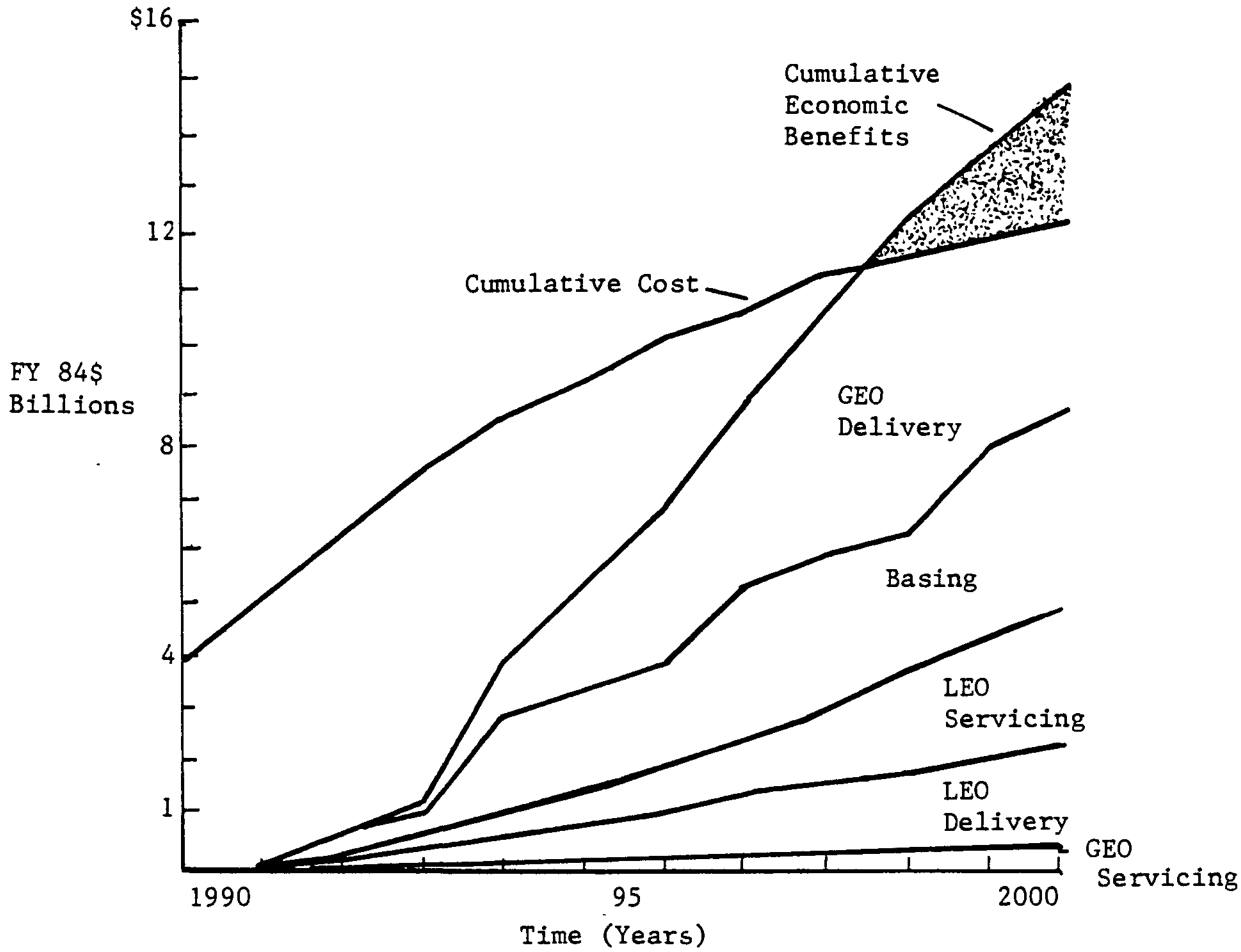


Figure 5.2-2 Cost/Benefit Breakeven Analysis - Modular Space Station 28.5°

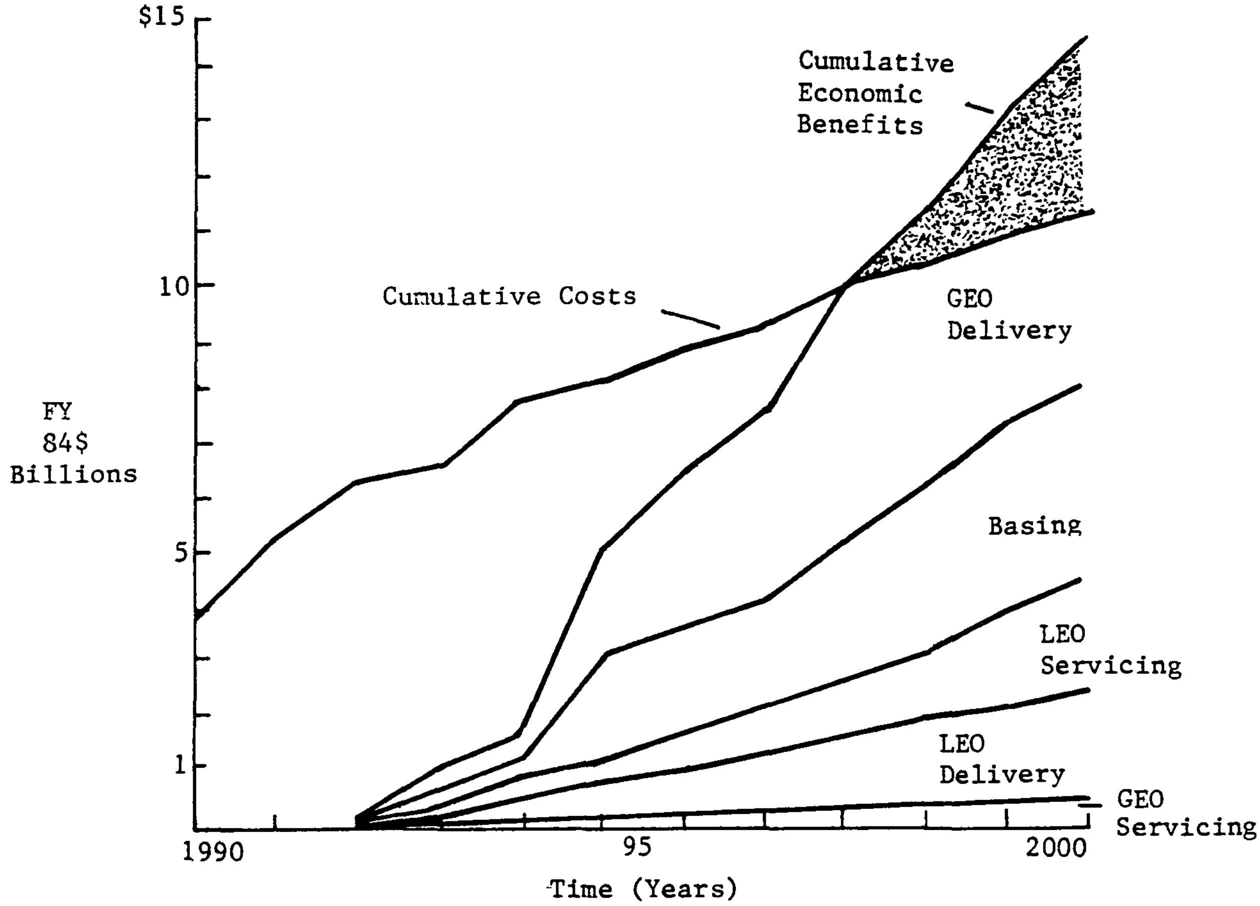


Figure 5.2-3 Cost/Benefit Breakeven Analysis - SDV Space Station 28.5°

The effect on cost was to lower the total peak fiscal funding required from about $1.8 billion to $1.4 billion. Peak funding required for the Modular Space Station Concept would be about $1.3 billion. Our total cost estimates for the Modular concept of Space Station assume an optimum program schedule. If a longer schedule were planned from the start of the program the effect on cost would be minimal. An unplanned schedule slip would have a much greater effect. We estimate that an unplanned one year slip in the scheduled IOC would result in a 15% increase in cumulative cost to IOC.

THIS PAGE INTENTIONALLY LEFT BLANK

6.0 COSTS

The objective of the cost analysis task is to prepare ROM cost estimates for each space station architecture studied in order to provide cost inputs to an economic analysis justification for manned space station design concepts that improve on the STS economics of space operations. The ROM cost estimates are presented by the NASA approved Work Breakdown Structure (WBS) to assure that all elements of cost are considered in the economic analysis task. Cost reported by WBS provides NASA with a basis for comparing competing design concepts and provides NASA with cost estimates that can be used to forecast phase C/D planning for new programs derived from this preliminary requirements study.

This section presents the space station cost task summary followed by the reporting of the cost estimates by WBS and by fiscal year funding.

6.1 COST SUMMARY

Our estimates of space station costs from ATP through 10 years of evolution and operation are shown in Table 6.1-1 for each of the three architectural options as described in section 3.0 Program Description.

Space station costs by evolution increment are shown in Figures 6.1-1 and 6.1-2 for a modular concept and a Shuttle Derived Vehicle concept respectively. The plot of cost versus fiscal year is cumulative cost and includes design development, test and evaluation costs, production costs, initial launch costs, and operations costs. The acquisition costs for a modular concept apply to either an STS orbiter modular concept or to an ACC modular concept. The preliminary ROM nature of the cost analysis combined with the early conceptual design data available at this time does not indicate a significant difference in the development or production cost of the modular options. The launch operations cost estimate for an ACC modular concept differs from the 14-foot modular concept by \$220M, or two less flights, due to the added payload volume of the ACC.

The SDV concept does permit cost avoidance in the areas of structure design, fabrication, and assembly and system test and integration. A significant cost avoidance is realized in launch costs if an SDV vehicle is used to launch the SDV space station module. The development cost of the SDV launch vehicle itself is not included in the SDV space station cost estimate. If space station were the only program that required the SDV, approximately \$2.4 billion would be added to the space station development cost. The space station costs were estimated parametrically by element. Our parametric analysis used cost estimating relationships (CERs) from the Martin Marietta Cost Analysis Data Books (CADBs). These CERs are based on similar major programs such as Skylab and Shuttle.

Table 6.1-1 Summary Cost By Architectural Option

	Cost FY84 $ In Millions				
Option	DDT&E	Prod.	Launch	Ops	Total
Modular 14' Diameter	$2470	$5255	$2030	$2520	$12,275
Modular ACC	2470	5255	1810	2520	12,055
Shuttle Derived Vehicle	2430	5135	1370	2520	11,455

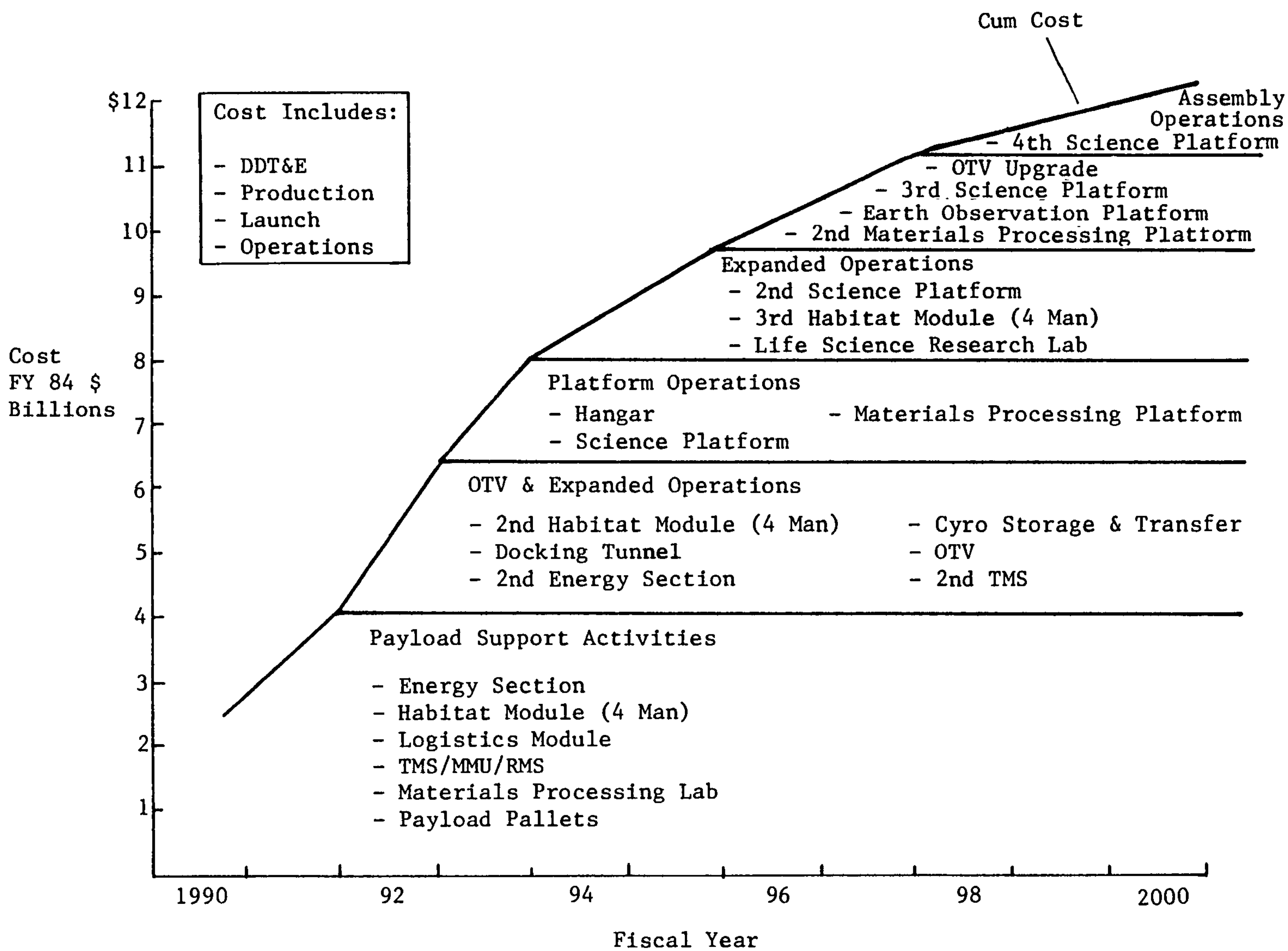


Figure 6.1-1 Space Station Cost by Evolution Increment - Modular Concept

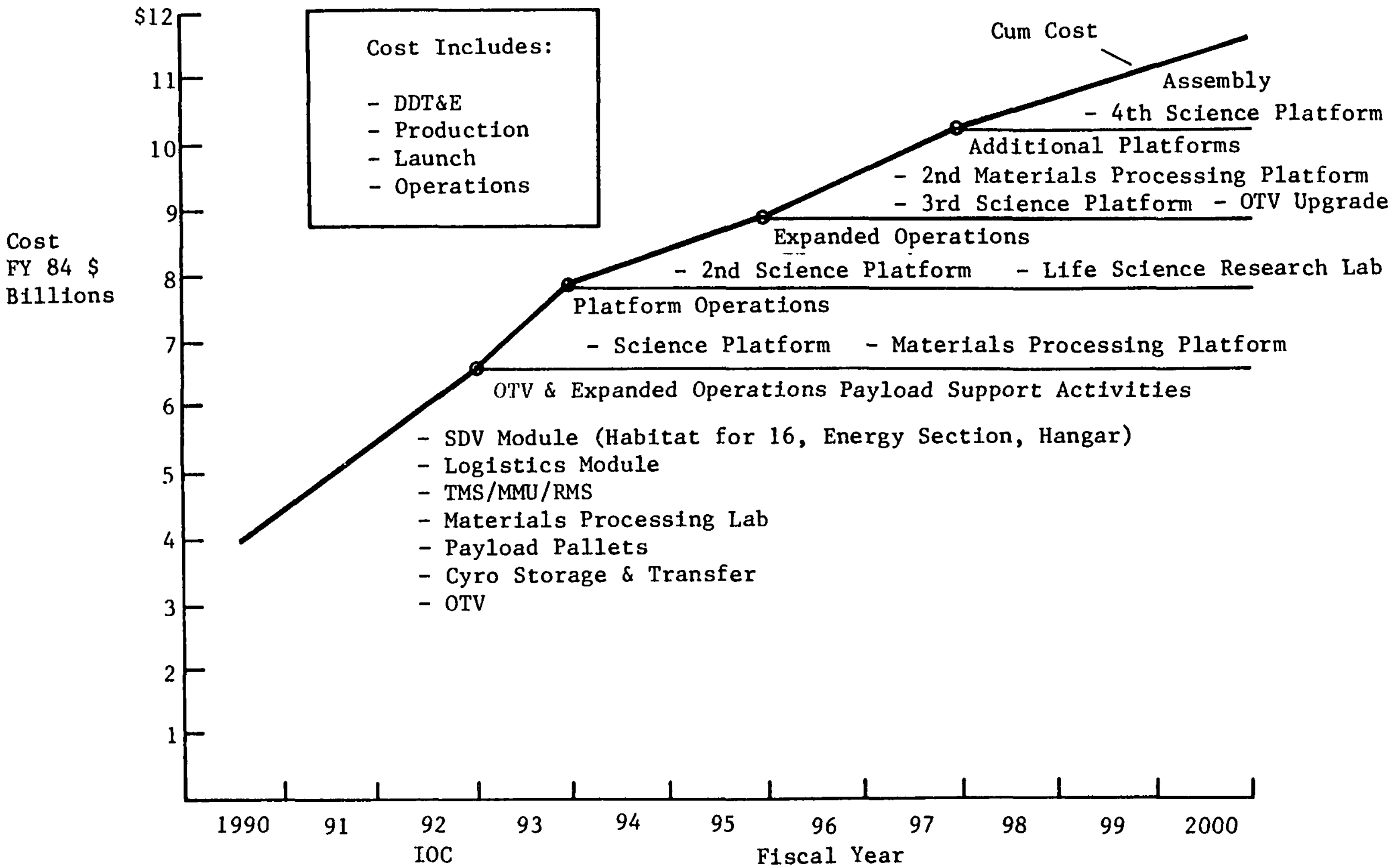


Figure 6.1-2 Space Station Cost By Evolution Increment - SDV Option

Table 6.1-2 Space Station Cost by Evolution Increment-Modular Option

Fiscal Year	Element	Costs FY 84 $ Millions Acq.	Launch	Ops	Total	Cum Total
1990	Energy Section #1 w/Airlock	$ 830	$ 110	$–	$ 940	$ 940
	Habitat Module	1,300	110	–	1,410	
	TMS	30	15	–	45	
	SE&I	450	–	–	450	2,845
1991	Logistics Module w/ Propellant Storage	425	75	–	500	
	Payload Pallets	95	110	–	205	
	MMU/RMS	30	–	–	30	
	Material Proc Lab	235	55	–	290	
	SE&I/Ops	150	–	150	300	4,170
1992	2nd HAB Module	630	110	–	740	
	Docking Tunnel Section	130	110	–	240	
	2nd Energy Section	395	110	–	505	
	Cyro Storage & Transfer	145	55	–	200	
	OTV	50	55	–	105	
	2nd TMS	30	15	–	45	
	SE&I/Ops	265	–	220	485	6,490
1993	Hangar	245	110	–	355	
	Science Platform (ISTO/ASO)	485	110	–	595	
	Materials Processing Platform	170	110	–	280	
	SE&I/Ops	50	–	220	270	7,990
1994	2nd Science Platform	120	110	–	230	
	SE&I/Ops	30	–	220	250	8,470
1995	3rd HAB Module	630	110	–	740	
	Life Sciences Research Lab	170	55	–	225	
	SE&I	25	–	285	310	9,745
1996	Earth Observation Platform	170	110	–	280	
	SE&I/Ops	15	–	285	300	10,325
1997	2nd Materials Proc. Platform	120	110	–	230	
	OTV Upgrade/Mod	50	55	–	105	
	3rd Science Platform	120	110	–	230	
	SE&I/Ops	10	–	285	295	11,185
1998	Ops	5	–	285	290	11,475
1999	4th Science Platform	120	110	–	230	
	SE&I/Ops	–	–	285	285	11,990
2000	Ops	–	–	–	285	
	Total	$ 7,725	$2,030	$2,520		$12,275

Table 6.1-3 Space Station Cost by Evolution Increment—SDV Option

		Costs FY 84 $ Millions				
Fiscal Year	Element	Acq.	Launch	Ops	Total	Cum Total
1992	SDV Module	$4,000	$ 110	$–	$4,110	$
	Logistics Modules w/Propellant Storage	425	75	–	500	
	Payload Pallets	95	110	–	205	
	MMU/RMS	30	–	–	30	
	Materials Processing Lab	235	55	–	290	
	Cyro Storage & Transfer	145	55	–	200	
	OTV	50	55	–	105	
	TMS	60	30	–	90	
	SE&I/Ops	865	–	220	1,085	
						6, 6,615
1993	*Science Platform (ISTO/ASO)*	485	110	–	595	
	Materials Processing Platform	170	110	–	230	
	SE&I/Ops	50	–	220	270	
						7,760
1994	2nd Science Platform	120	110	–	230	
	SE&I/Ops	30	–	220	250	
						8,242
1995	Life Sciences Research Lab	170	55	–	225	
	SE&I	25	–	285	310	
						8,775
1996	Earth Observation Platform	170	110	–	280	
	SE&I/Ops	15	–	285	300	
						9,355
1997	2nd Materials Proc. Platform	120	110	–	230	
	OTV Upgrade/Mod	50	55	–	105	
	3rd Science Platform	120	110	–	230	
	SE&I/Ops	10	–	285	295	
						10,215
1998	Ops	5	–	285	290	
						10,505
1999	4th Science Platform	120	110	–	230	
	SE&I/Ops	–	–	285	285	
						11,020
2000	Ops	–	–	–	150	
	Total	$ 7,565	$1,370	$2,520		$11,455

Launch costs are based on an average cost per flight in the early 1990s of $47.4 million in FY 1975 dollars or $110 M per flight in 1984 dollars for a launch from KSC. These costs are based on a 24 flight per year mission model. Launch costs from VAFB at a 6 flight per year rate would be $66.3 million in FY 1975 dollars or $150 million in FY 1984 dollars.

Operations costs were assumed to be equal for any of the concepts since crew size would be evolved at the same rate for each concept. Operations costs include the cost of shuttle resupply flights on a cost share basis, replacement spares cost, consumables and a ground and flight crew of 100 people.

6.2 COST BY WORK BREAKDOWN STRUCTURE

Space station cost estimates for each option were prepared according to the NASA WBS and are presented according to the data form A format suggested at the Study orientation briefing. Cost estimates are reported to WBS level 3 for all elements with the exception of the spacecraft segment which presents cost data to level 4, the space station hardware module level. No costs are reported for the payload segment as these costs were excluded from this study. Also, manufacturing and launch facilities are assumed to exist and, consequently no costs are reported in the WBS.

The design, development, test and evaluation (DDT&E) costs include design and development of each hardware module; software development for all modules; level II and III system integration, program management, GSE, assembly and test for all space station hardware. Recurring production cost estimates include the protoflight article hardware fabrication and refurbishment; initial spares for all hardware; integration, assembly and test for all hardware; and sustaining engineering and program management. The second flight article cost estimate, where applicable, excludes refurbishment costs.

The space station cost estimates by WBS for the modular 14-foot option are presented in Table 6.2-1 through 6.2-5. Table 6.2-1 shows the WBS cost estimates summarized to level 1 and 2. The modular 14-foot diameter option cost estimate is $12.2B. Because of the ROM nature of the cost estimates based on preliminary space station hardware definition, a cost range has been added to bound the uncertainty inherent in the cost estimating techniques. Space station estimates could vary from approximately $10-15B in 1984 dollars. Subsequent detailed cost estimates by lower level WBS are contained in Tables 6.2-2 through 6.2-5.

Table 6.2-1 Space Station Cost Estimates By WBS - Modular -14' Diameter Option Summary

WBS			No. Of Units	FY 84 Dollars in Billions					
				Non-Recurring DDT&E	Recurring		Total	Cost Range	
Number	Title	Level			Production	Operations		Low	High
1.0	Space Station	1	1	2.4	5.2	4.6	12.2	10	15
1.1	Spacecraft Segment	2	All	2.0	4.7	0.5	7.2	6	9
1.2	Payload Segment	2	--	--	--	--	(1)	--	--
1.3	Space Transportation Segment	2	All	--	--	4.0	4.0	3	5
1.4	Ground Segment	2	All	0.1	--	0.1	0.2	0.1	0.3
1.5	System Level Integration and Test	2	All	0.3	0.5	--	0.8	0.5	1.5

Note: (1) Excluded From Space Station Costs

Table 6.2-2 Space Station Cost Estimates By WBS - Modular -14' Diameter Option Spacecraft Segment Summary

WBS			No. Of Units	FY 84 Dollars in Millions			
				Non-Recurring DDT&E	Recurring		Total
Number	Title	Level			Production	Operations	
1.1	Spacecraft Segment	2	1	2,000	4,725	475	7,200
1.1.1	Hardware	3	All	1,560	3,425	--	4,985
1.1.2	Software	3	All	150	--	75	225
1.1.3	Services	3	All	290	1,300	400	1,990
1.1.4	Facilities	3	All	--	--	--	(1)

Note: (1) Manufacturing Facilities Exist

Table 6.2-3 Space Station Cost Estimates By WBS - Modular -14' Option Spacecraft Segment

WBS			No. Of Units	FY 84 Dollars in Millions			
				Non-Recurring DDT&E	Recurring		Total
Number	Title	Level			Production	Operations	
1.1.1	Hardware	3	All	1,560	3,425	--	4,985
1.1.1.1	Integration, Assembly, and Test	4	All	190	340	--	530
1.1.1.10	Energy Section	4	2	235	430	--	665
1.1.1.11	Habitat Module	4	3	290	1,090	--	1,380
1.1.1.12	Logistics Module	4	2	75	160	--	235
1.1.1.13	Materials Processing Lab	4	1	65	65	--	130
1.1.1.14	Man Maneuvering Unit	4	1	--	5	--	5
1.1.1.15	Remote Manipulator System	4	1	20	5	--	25
1.1.1.16	Teleoperator Maneuvering System	4	1	--	60	--	60
1.1.1.17	Docking Tunnel	4	1	30	40	--	70
1.1.1.18	Cryo Storage and Transfer	4	1	50	30	--	80
1.1.1.19	Reusable OTV	4	1	--	100	--	100
1.1.1.20	Hangar	4	1	85	50	--	135
1.1.1.21	Science Platforms	4	4	240	330	--	570
1.1.1.22	Materials Processing	4	2	35	170	--	205
1.1.1.23	Life Science Module	4	1	35	85	--	120
1.1.1.24	Earth Observation Platform	4	1	35	85	--	120
1.1.1.25	Payload Pallets	4	5	15	40	--	55
1.1.1.50	GSE	4	All	160	(2)	--	160
1.1.1.90	Hardware Support	4	All	(1)	340	--	340

Notes: (1) Included in Production
(2) Included in DDT&E

Table 6.2-4 Space Station Cost By WBS - Modular 14' Diameter Option Space Transporation Segment

WBS			No. Of Units	FY 84 Dollars in Millions			
				Non-Recurring DDT&E	Recurring		Total
Number	Title	Level			Production	Operations	
1.3	Space Transporation Segment	2	All	--	--	4,050	4,050
1.3.1	Hardware	3	All	--	--	--	(1)
1.3.2	Software	3	All	--	--	--	(2)
1.3.3	Services	3	All	--	--	4,050	4,050
1.3.4	Facilities	3	All	--	--	--	(3)

Notes: (1) All Hardware Exists
(2) All Software Exists
(3) All Launch Facilities Exist

Table 6.2-5 Space Station Cost by WBS - Modular 14' Diameter Option - Ground Segment

WBS			No. Of Units	FY 84 Dollars in Millions			
				Non-Recurring DDT&E	Recurring		Total
Number	Title	Level			Production	Operations	
1.4	Ground Segment	2	All	80	--	100	180
1.4.1	Hardware	3	All	--	--	--	(1)
1.4.2	Software	3	All	80	--	--	80
1.4.3	Services	3	All	--	--	100	100
1.4.4	Facilities	3	All	--	--	--	(2)

Notes: (1) Included in WBS 1.1.1.50
(2) All Ground Facilities Exist

The space station cost estimates by WBS for the ACC modular option are shown in Tables 6.2-6 and 6.2-7. As previously stated, the ACC concept has the same estimated DDT&E and production cost estimates as the modular 14-foot diameter option. Consequently, only the WBS elements that have changed, namely the transportation segment launch costs, are reported for the ACC modular option. The ACC modular space station option cost estimate is $12.0B and exhibits the same cost uncertainty as previously discussed.

The space station cost estimates by WBS for the SDV option are presented in Tables 6.2-8 through 6.2-12. The summary WBS cost estimates shown in Table 6.2-8 indicate the SDV space station option cost is $11.4B. This option provides an estimated cost avoidance of at least $0.6B compared to both modular options due to lower launch costs for the large volume SDV space station.

The space station cost estimates by WBS have been ranked for both the DDT&E and production cost phase to identify the program cost drivers (Figures 6.2-1 and 6.2-2). The top line DDT&E cost drivers are the habitat module, system engineering/program management, initial platform development, energy sections and systems integration/test. The production phase cost drivers are systems integration, program management and mission support; habitat modules; energy sections; initial spares; and sustaining engineering, assembly and test.

6.3 COST BY FISCAL YEAR

The WBS cost estimates by fiscal year for the modular and SDV options are shown in Figures 6.3-1 and 6.3-2 respectively. These cost time distributions were developed using the program evolution schedule shown in Figure 7.1-2. Each program cost element (DDT&E, production and operations) was spread using a computer model that calculates cost distribution curves defined by Beta spread functions. The form of the spread function was developed by the NASA. We used spread functions that are typical for development programs and follow-on build programs.

The cost by fiscal year start at ATP for a phase C/D development program. The cost for the modular space station option assumes an IOC date of 1991. In order to meet the affordability criteria for space station the SDV concept space station costs are spread assuming an IOC date of 1992. This lowers the early fiscal year development costs for an SDV concept so they are equal to or less than a modular concept.

The peak annual funding for the modular concepts is $1.3B and occurs in FY 3 and 4. The peak annual funding for the SDV concept is $1.4B and occurs in FY 4 and 5.

Table 6.2-6 Space Station Cost Estimates By WBS - ACC Modular Option Summary

				FY 84 Dollars in Billions					
WBS			No. Of Units	Non-Recurring DDT&E	Recurring		Total	Cost Range	
Number	Title	Level			Production	Operations		Low	High
1.0	Space Station	1	1	2.4	5.2	4.4	12.0	10	15
1.1	Spacecraft Segment	2	All	2.0	4.7	0.5	7.2	6	9
1.2	Payload Segment	2	All	--	--	--	(1)	--	--
1.3	Space Transportation Segment	2	All	--	--	3.8	3.8	3	5
1.4	Ground Segment	2	All	0.1	--	0.1	0.2	0.1	0.3
1.5	Systems Level Integration and Test	2	All	0.3	0.5	--	0.8	0.5	1.5

Note: (1) Excluded From Space Station Costs

Table 6.2-7 Space Station Cost By WBS - ACC Modular Option Space Transporation Segment

WBS			No. Of Units	FY 84 Dollars in Millions			
				Non-Recurring DDT&E	Recurring		Total
Number	Title	Level			Production	Operations	
1.3	Space Transportation Segment	2	All	--	--	3,810	3,810
1.3.1	Hardware	3	All	--	--	--	(1)
1.3.2	Software	3	All	--	--	--	(2)
1.3.3	Services	3	All	--	--	3,810	3,810
1.3.4	Facilities	3	All	--	--	--	(3)

Notes: (1) All Hardware Exists
(2) All Software Exists
(3) All Launch Facilities Exist

Table 6.2-8 Space Station Cost By WBS - SDV Option Summary

WBS			No. Of Units	FY 84 Dollars in Billions					
				Non-Recurring DDT&E	Recurring		Total	Cost Range	
Number	Title	Level			Production	Operations		Low	High
1.0	Space Station	1	1	2.4	5.1	3.9	11.4	10	15
1.1	Spacecraft Segment	2	All	2.1	4.6	0.5	7.2	6	9
1.2	Payload Segment	2	All	--	--	--	(1)	--	--
1.3	Space Transportation Segment	2	All	--	--	3.3	3.3	3	5
1.4	Ground Segment	2	All	0.1	--	0.1	0.2	0.1	0.3
1.5	System Level Integration and Test	2	All	0.2	0.5	--	0.7	0.5	1.5

Note: (1) Excluded From Space Station Costs

Table 6.2-9 Space Station Cost Estimates By WBS - SDV Option Spacecraft Summary

WBS			No. Of Units	FY 84 Dollars in Millions			
				Non-Recurring DDT&E	Recurring		Total
Number	Title	Level			Production	Operations	
1.1	Spacecraft Segment	2		2,045	4,620	475	7,140
1.1.1	Hardware	3	All	1,510	3,340	--	4,850
1.1.2	Software	3	All	150	--	75	225
1.1.3	Services	3	All	385	1,280	400	2,065
1.1.4	Facilities	3	All	--	--	--	(1)

Notes: (1) Manufacturing Facilities Exist

Table 6.2-10 Space Station Cost Estimates By WBS - SDV Option Spacecraft Segment

WBS				FY 84 Dollars in Millions			
				Non-Recurring	Recurring		
Number	Title	Level	No. Of Units	DDT&E	Production	Operations	Total
1.1.1	Hardware	3	All	1,510	3,340	--	4,850
1.1.1.1	Integration, Assembly, and Test	4	All	160	285	--	445
1.1.1.10	Energy Section	4	1	230	430	--	660
1.1.1.11	Habitat Module	4	1	285	1,065	--	1,350
1.1.1.12	Logistics Module	4	2	75	160	--	235
1.1.1.13	Materials Processing Lab	4	1	65	65	--	130
1.1.1.14	Man Maneuvering Unit	4	1	--	5	--	5
1.1.1.15	Remote Manipulator System	4	1	20	5	--	25
1.1.1.16	Teleoperator Maneuvering System	4	2	--	60	--	60
1.1.1.17	Docking Tunnel	4	1	30	40	--	70
1.1.1.18	Cryo Storage and Transfer	4	1	50	30	--	80
1.1.1.19	Reusable OTV	4	2	--	100	--	100
1.1.1.20	Hangar	4	1	80	50	--	130
1.1.1.21	Science Platforms	4	4	240	330	--	570
1.1.1.22	Materials Processing	4	2	35	170	--	205
1.1.1.23	Life Science Module	4	1	35	85	--	120
1.1.1.24	Earth Observation Platform	4	1	35	85	--	120
1.1.1.25	Payload Pallets	4	5	15	40	--	55
1.1.1.50	GSE	4	All	155	(2)	--	155
1.1.1.90	Hardware Support	4	All	(1)	335	--	335

Notes: (1) Included in Production
(2) Included in DDT&E

Table 6.2-11 Space Station Cost Estimates by WBS - SDV Option, Space Transportation Segment

WBS			No. Of Units	FY 84 Dollars in Millions			
				Non-Recurring DDT&E	Recurring		Total
Number	Title	Level			Production	Operations	
1.3	Space Transportation Segment	2	All	--	--	3,290	3,290
1.3.1	Hardware	3	All	--	--	--	(1)
1.3.2	Software	3	All	--	--	--	(2)
1.3.3	Services	3	All	--	--	3,290	3,290
1.3.4	Facilities	3	All	--	--	--	(3)

Notes: (1) All Hardware Exists
(2) All Software Exists
(3) All Launch Facilities Exist

Table 6.2-12 Space Station Cost Estimates by WBS - SDV Option Ground Segment

WBS			No. Of Units	FY 84 Dollars In Millions			
				Non-Recurring	Recurring		Total
Number	Title	Level		DDT&E	Production	Operations	
1.4	Ground Segment	2	All	80	--	90	170
1.4.1	Hardware	3	All	--	--	--	(1)
1.4.2	Software	3	All	80	--	90	170
1.4.3	Services	3	All	--	--	--	
1.4.4	Facilities	3	All	--	--	--	(2)

Notes: (1) Included in WBS 1.1.1.50
(2) All Ground Facilities Exist

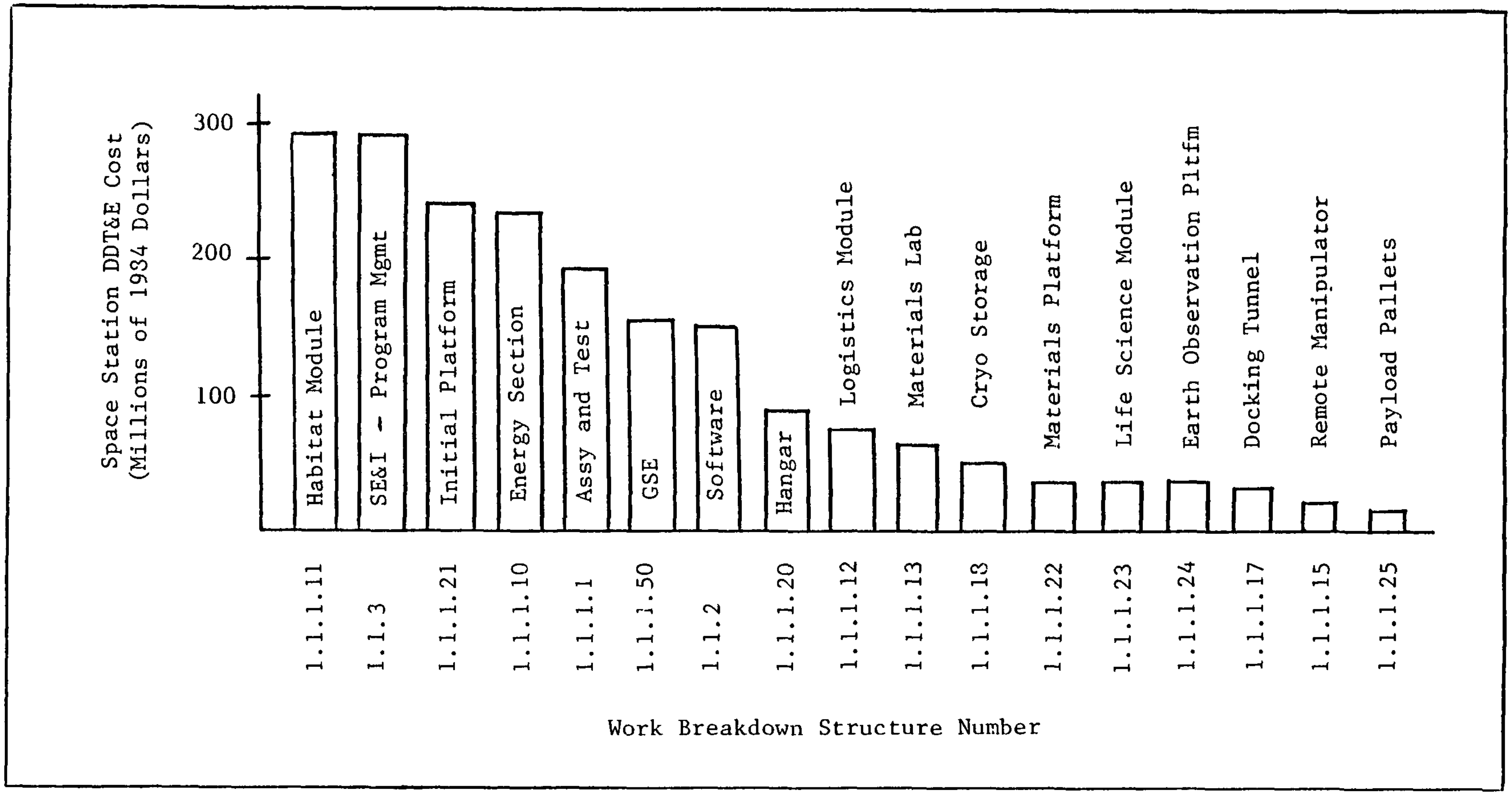


Figure 6.2-1 Space Station DDT&E Cost Drivers

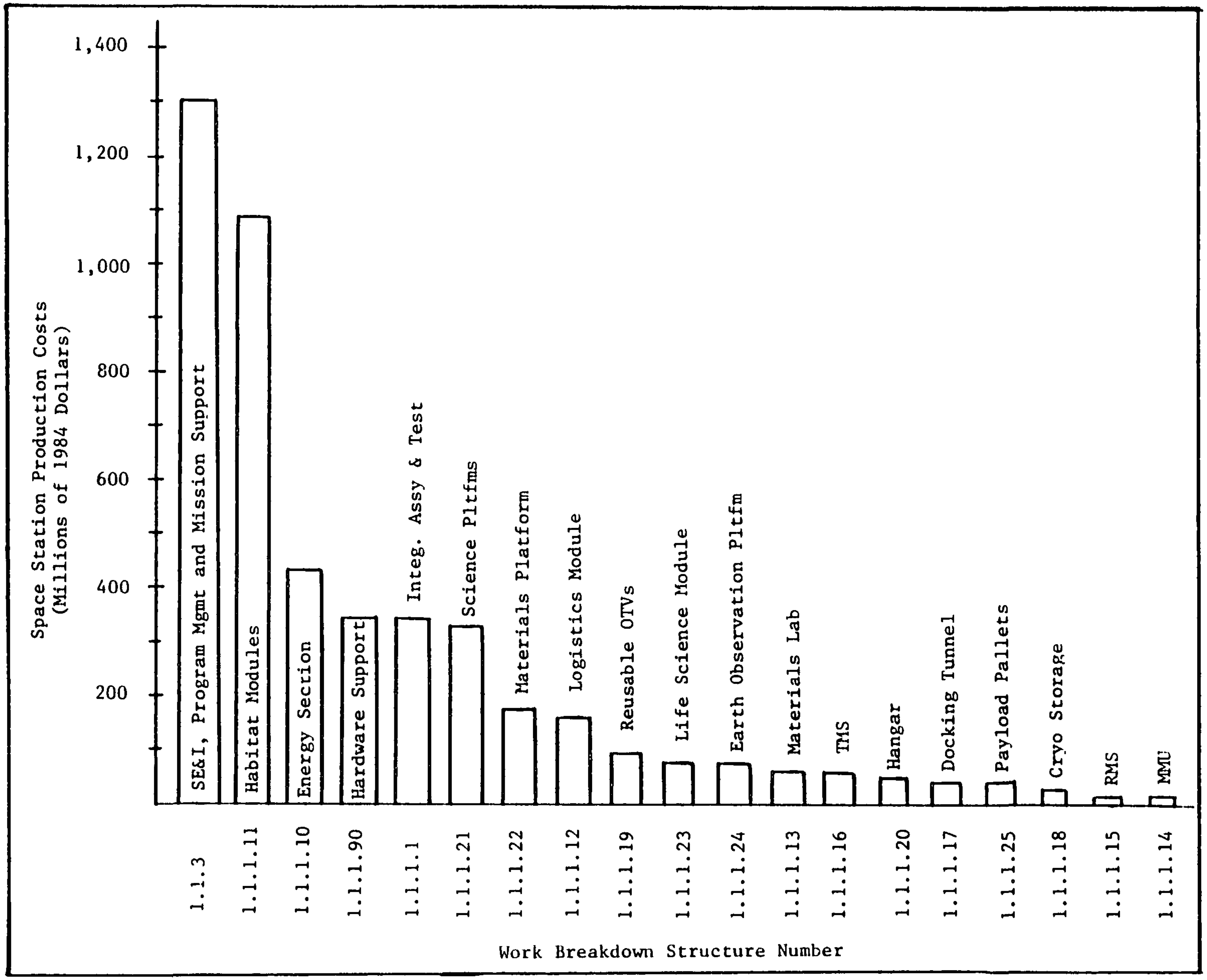
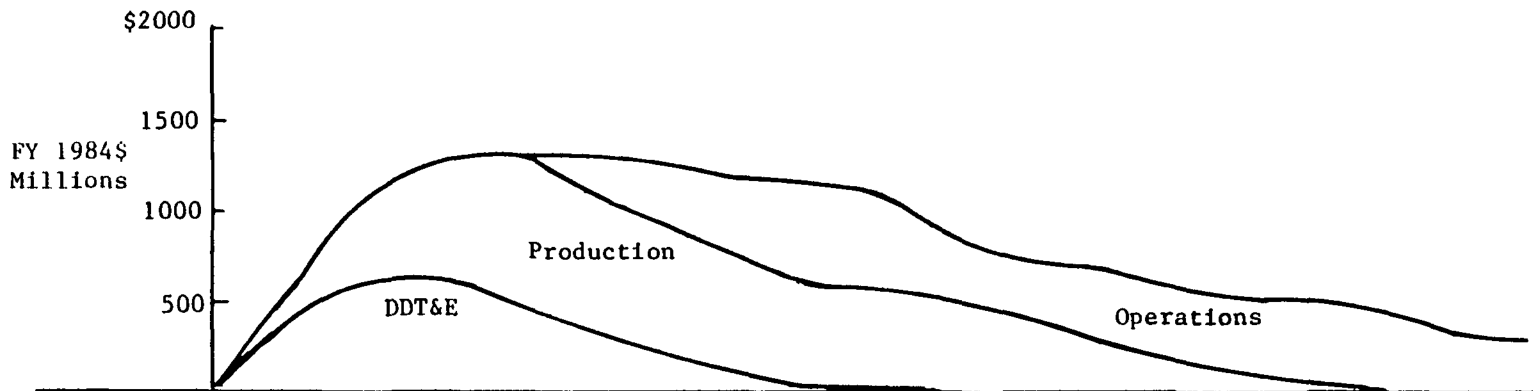
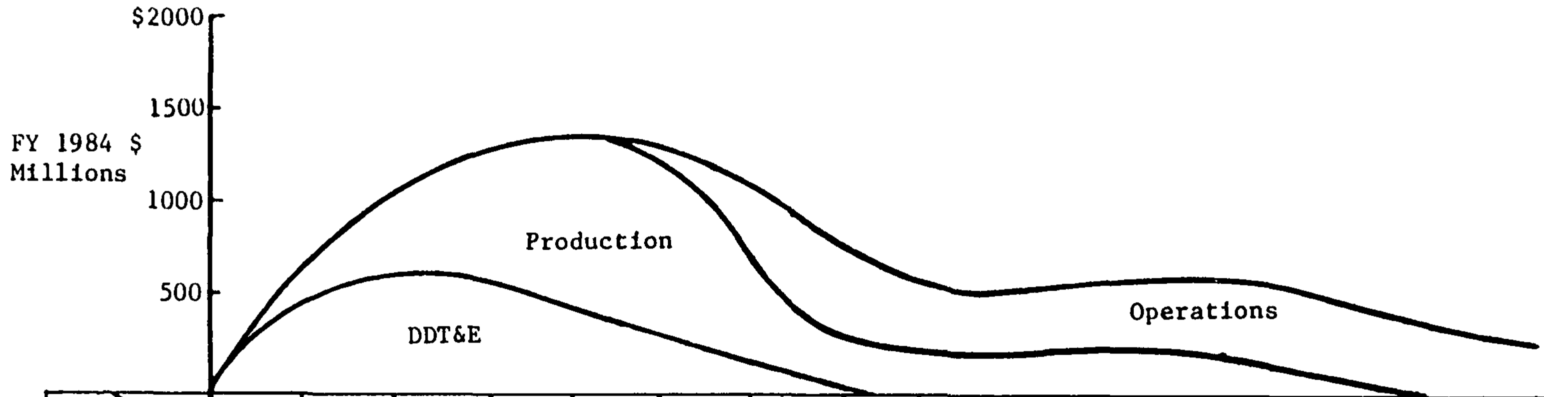


Figure 6.2-2 Space Station Production Cost Drivers



Cost Element \ FY	1986	1987	1988	1989	1990	(IOC) 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
DDT&E	290	590	600	480	300	140	45	10	10	5						2,470
Production		440	690	815	650	665	530	515	345	265	175	90	65	10		5,255
Operations					335	390	575	550	430	450	395	460	380	300	285	4,550
Total	290	1030	1290	1295	1285	1195	1150	1075	785	720	570	550	445	310	285	12,275

Figure 6.3-1 Cost by Fiscal Year - Modular Space Station Concept



Cost Element \ FY	1986	1987	1988	1989	1990	1991	(IOC) 1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
DDT&E	280	570	600	475	300	140	40	10	10	5						2,430
Production		330	655	890	1060	945	380	205	150	180	175	90	65	10		5,135
Operations						210	500	440	330	340	395	560	435	395	285	3,890
Total	280	900	1255	1365	1360	1295	920	655	490	525	570	650	500	405	285	11,455

Figure 6.3-2 Cost by Fiscal Year - SDV Space Station Concept

7.0 SCHEDULES

The schedules in this section represent our best judgment of development, test, fabrication and assembly span times for the space station program as described in Section 3.0 Program Description. They are based on analogy to Skylab and other major development programs but modified to fit our ground rules and assumptions for this program.

The summary program schedule was developed after preparing individual schedules for space station elements. The habitat module development schedule is the critical path to space station initial operational capability.

The key program assumptions that drive element schedules are that critical technology development would be completed before authority to proceed (ATP) on space station elements and a protoflight approach will require refurbishment time after development test is complete.

The program and element schedules in this section are shown by fiscal year (eg. FY1, FY2) as requested by the NASA, starting with ATP for a phase C/D development.

7.1 PROGRAM SCHEDULES

The Space Station program development schedule shown in Figure 7.1-1 summarizes the major activities and milestones required for space station development thru initial operational capability (IOC). The span times from ATP to Preliminary Design Review (PDR) and Critical Design Review (CDR) are typical for a large scale program such as this. The span from CDR to IOC is longer than a program with separate development and flight articles due to the required time to refurbish or replace components after qual and development tests. This protoflight approach adds about four to five months to the program schedule but we think the resultant cost avoidance of duplicate flight type hardware is a cost effective trade off.

The evolution of the space station is shown in Figure 7.1-2. This schedule shows the build up of the space station by element. The span times by element are from ATP for that element to launch of the element.

7.2 ELEMENT SCHEDULES

The space station element schedules were prepared based on analogy to similar hardware and adjusted for differences in complexity and program assumptions. The design spans show preliminary design to PDRs and detail design thru CDR. Not shown is the sustaining engineering that would continue until launch of each element. Long lead procurement was assumed to start after PDR, however for those time critical components that require longer lead times, procurement could start earlier.

Development test span times were based on judgment of the complexity of each element and amount of interface testing that will be required. A refurbishment time span was put in our schedules in series in accordance with our protoflight approach to space station development. This time is required to replace, repair or replenish components that might have been damaged or consumed during development test.

The integration span in the element schedules allows for interface mating tests and launch assembly and preparation. The launch milestone data is the time the element would be ready for launch. If a holding period were necessary in order to achieve efficient shuttle manifesting or space station buildup the element could be stored following refurbishment or integration tests.

Where multiple units of a space station element are required, as for the habitat module, we have shown a separate schedule of span times for build of subsequent flight units.

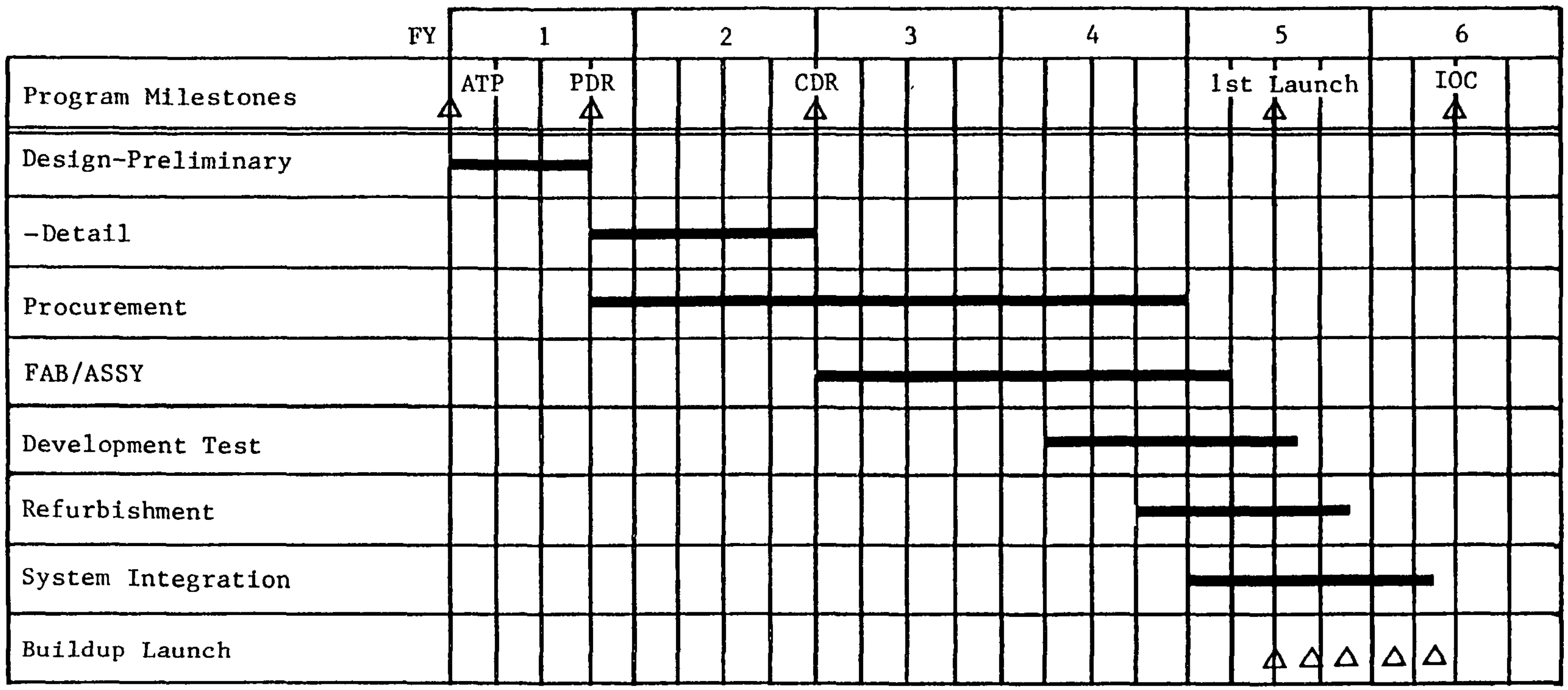


Figure 7.1-1 Space Station Program Development Schedule

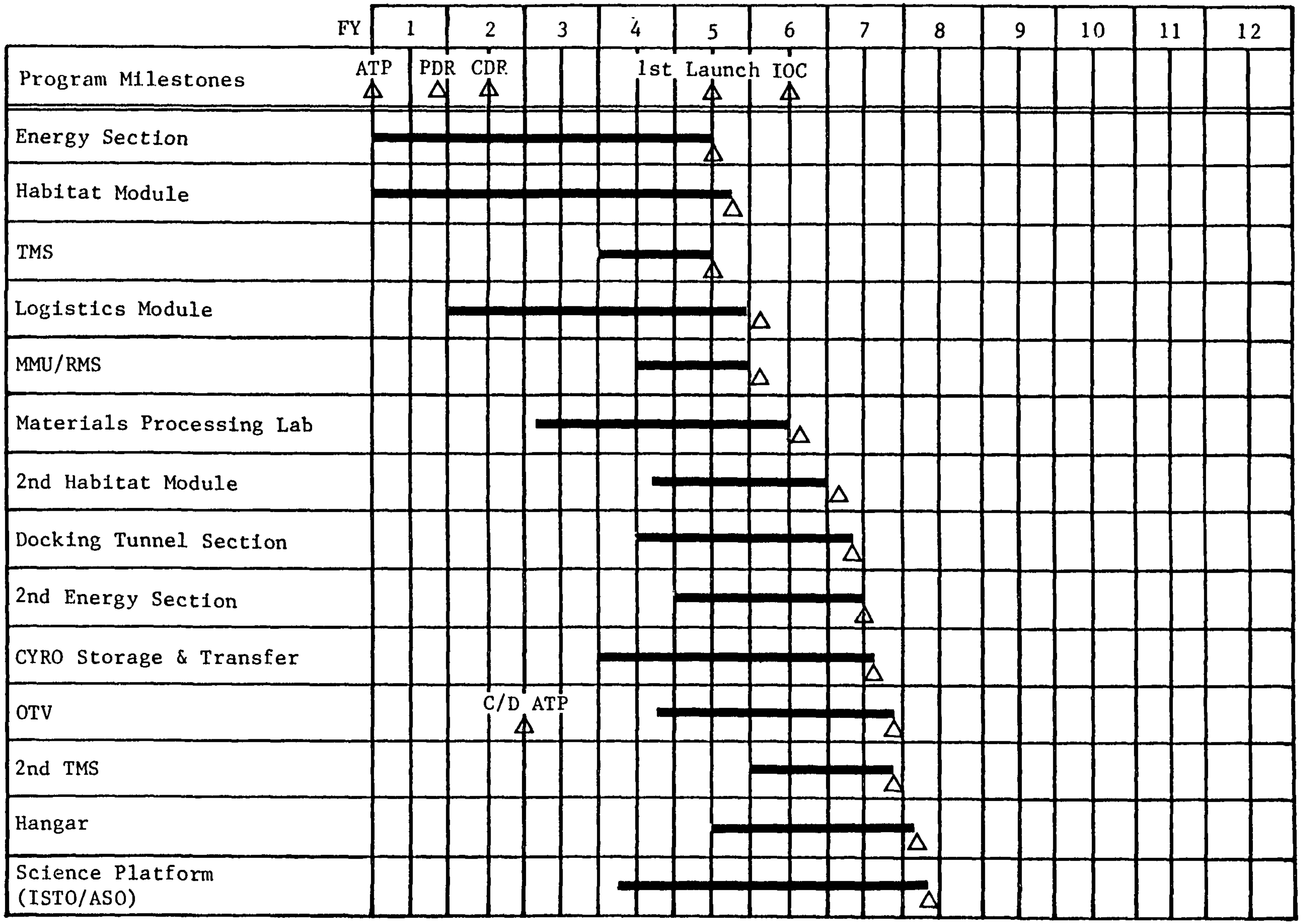


Figure 7.1-2 Space Station Program Evolution Schedule

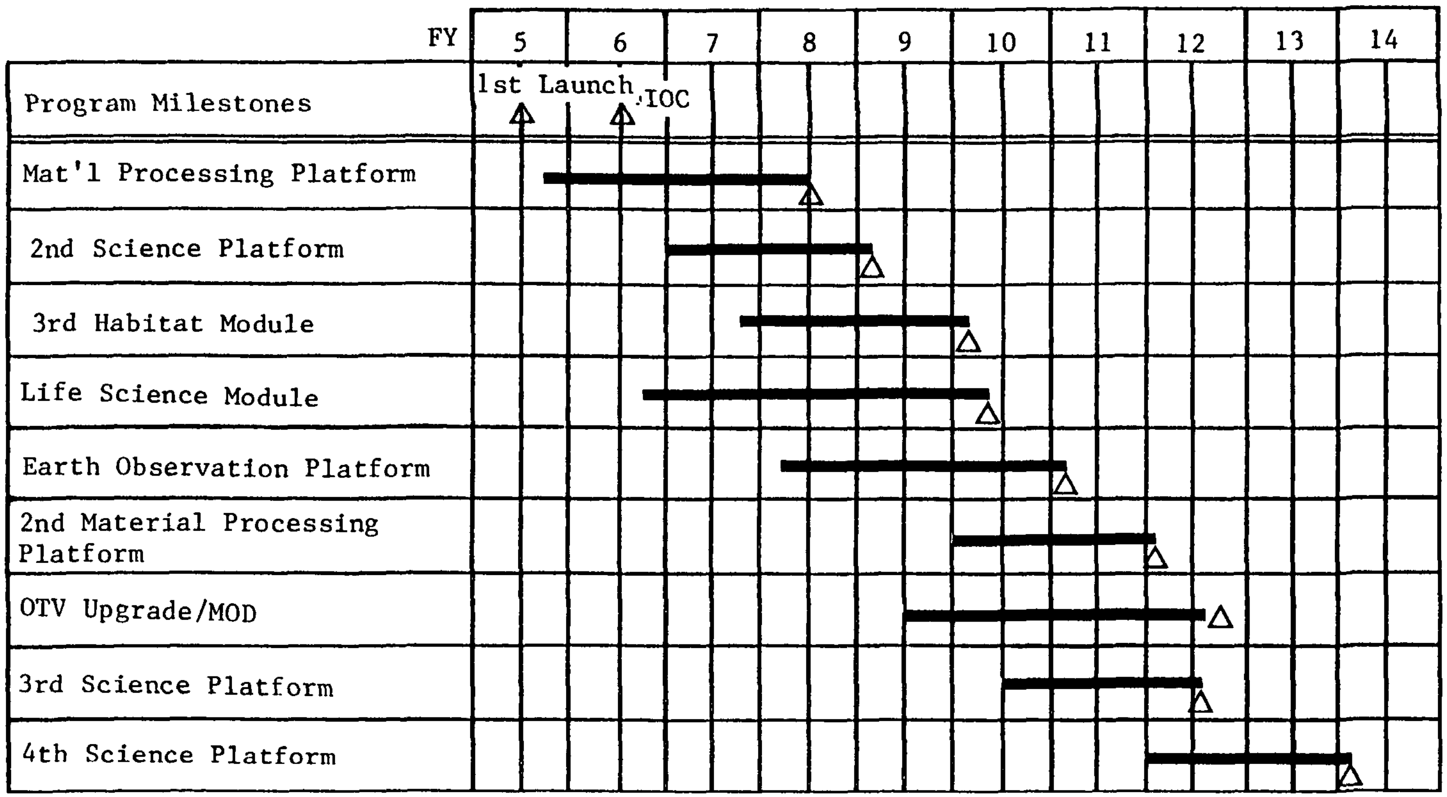


Figure 7.1-2 Space Station Program Evolution Schedule (Cont.)

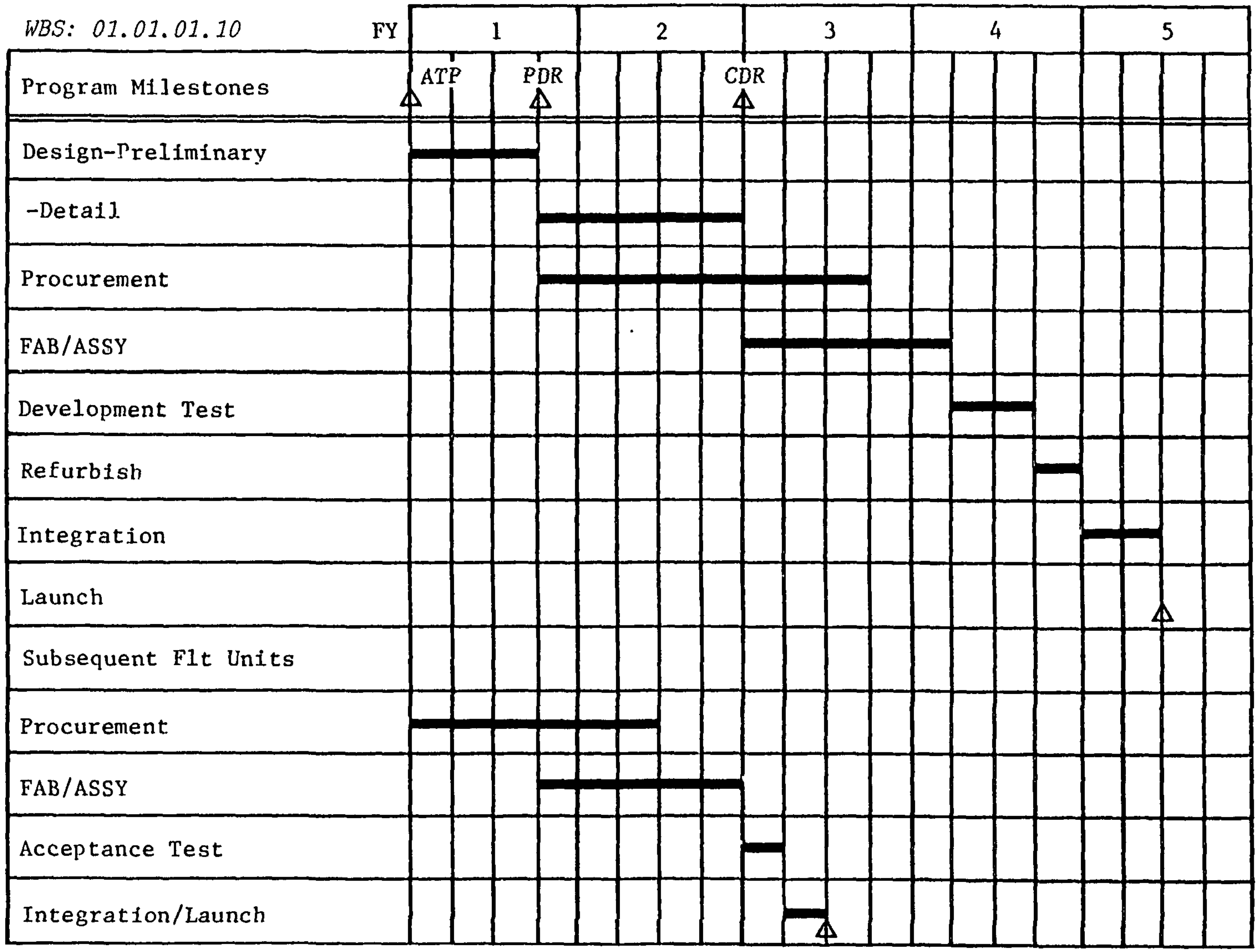


Figure 7.2-1 Space Station Element Schedule-Energy Section

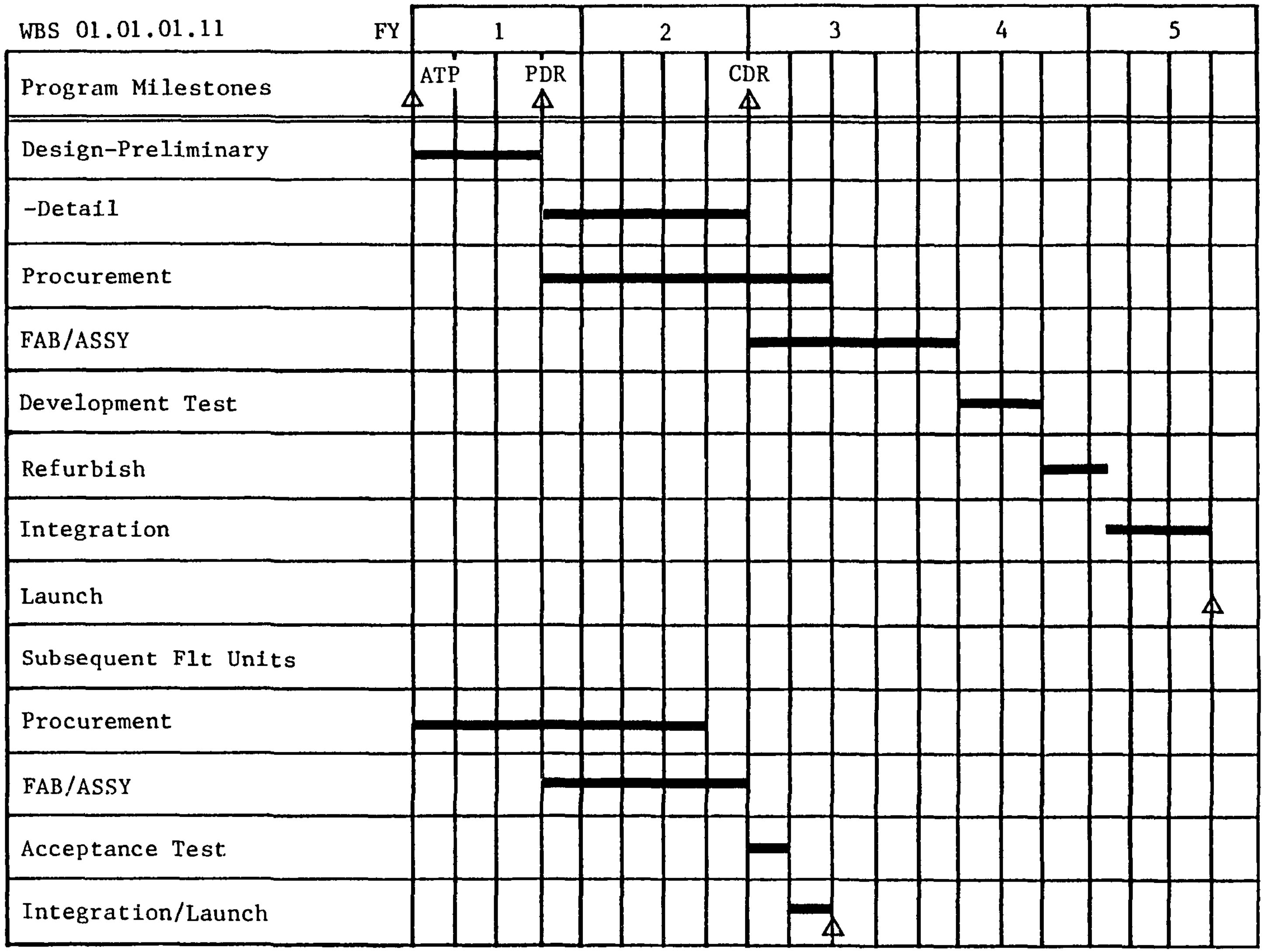


Figure 7.2-2 Space Station Element Schedule-Habitat Module

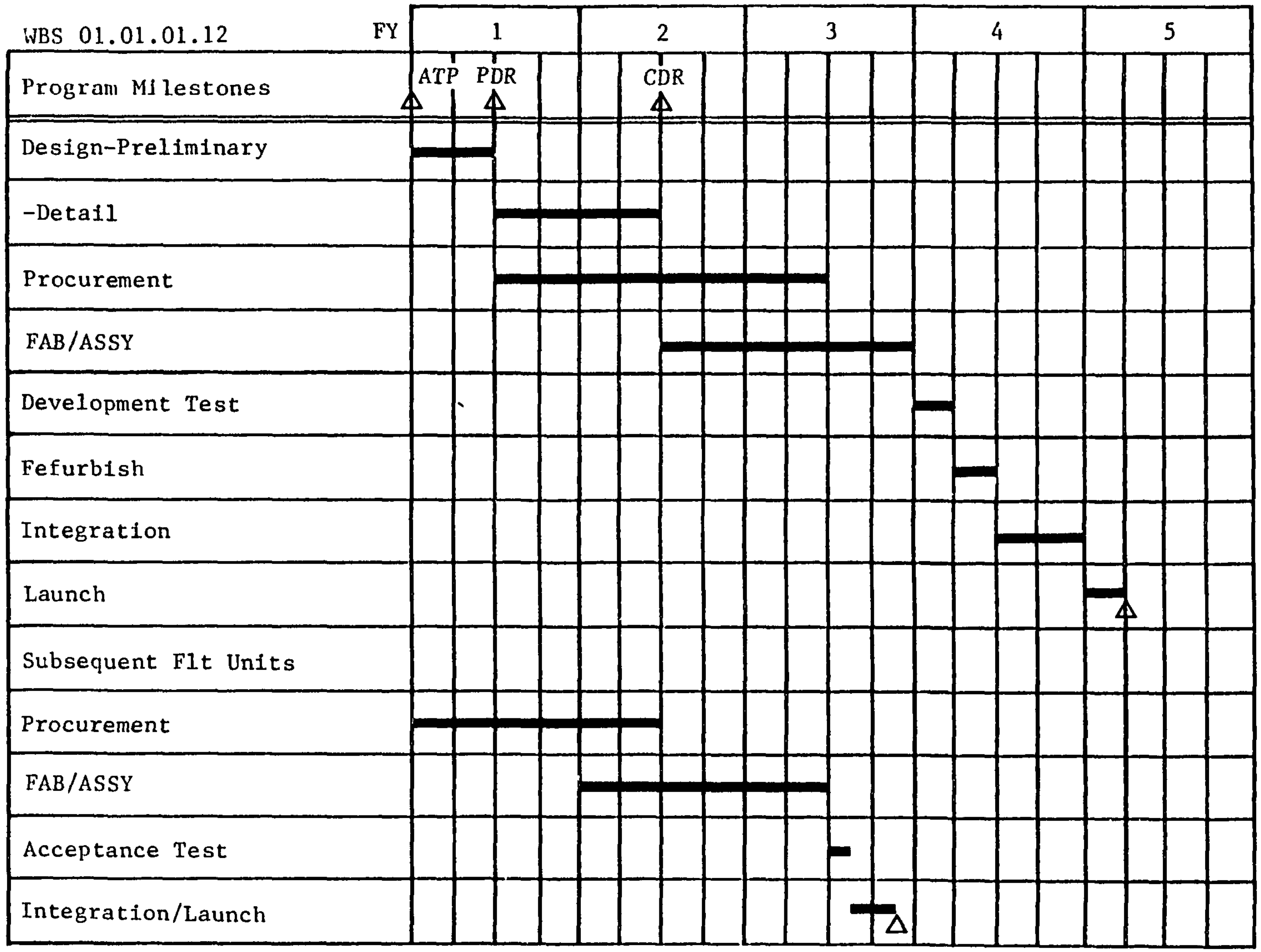


Figure 7.2-3 Space Station Element Schedule-Logistics Module

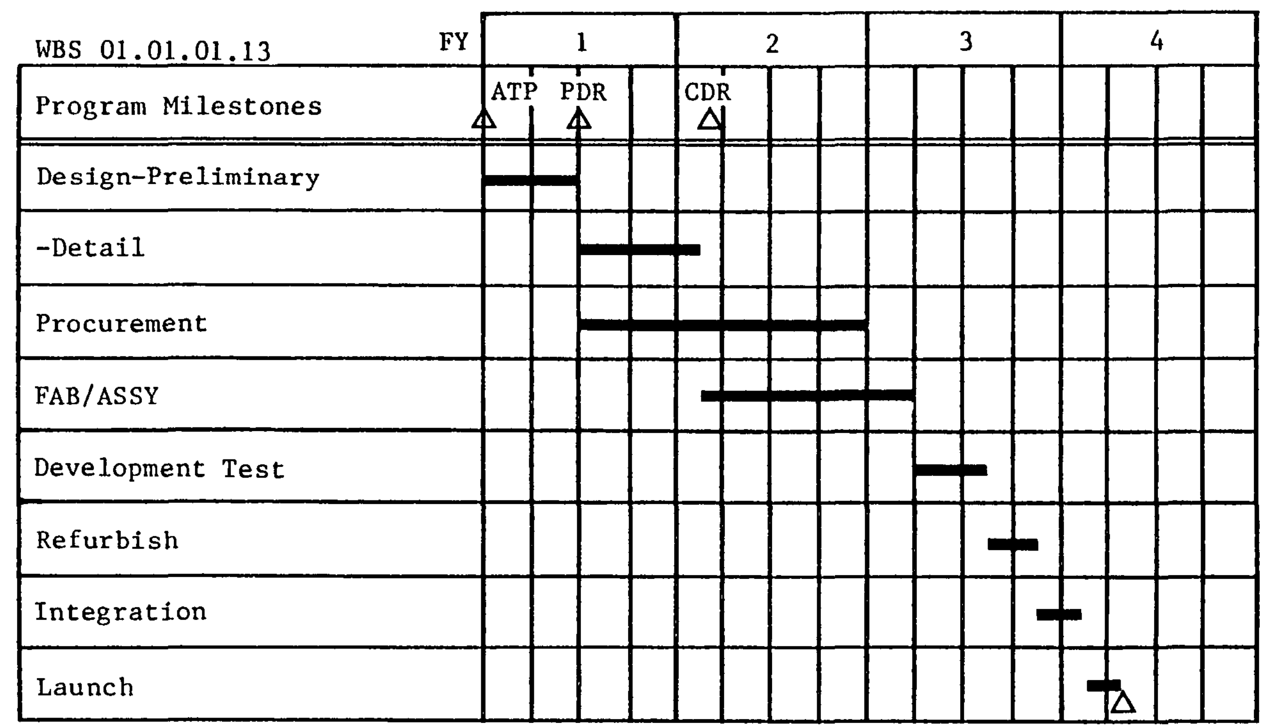


Figure 7.2-4 Space Station Element Schedule-Materials Processing Lab

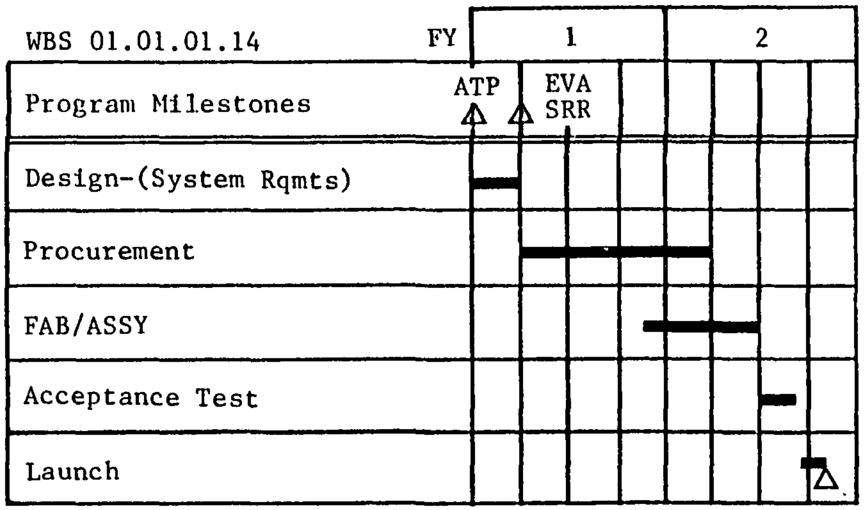


Figure 7.2-5 Space Station Element Schedule-Man Maneuvering Unit (MMU)

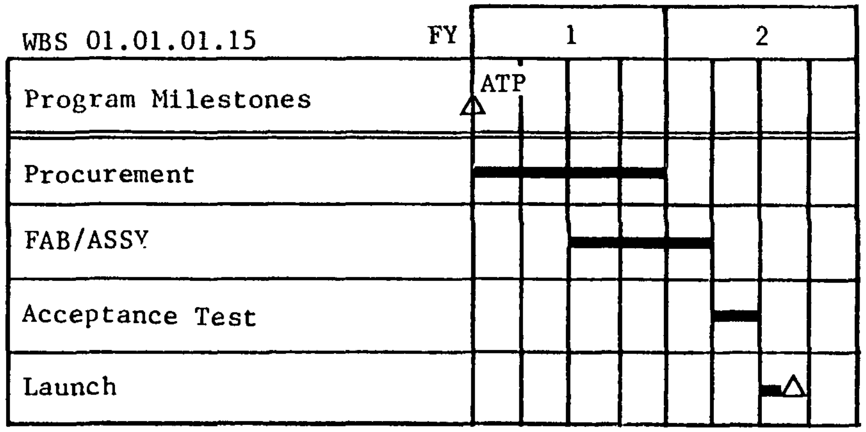


Figure 7.2-6 Space Station Element Schedule-Remote Manipulator System (RMS)

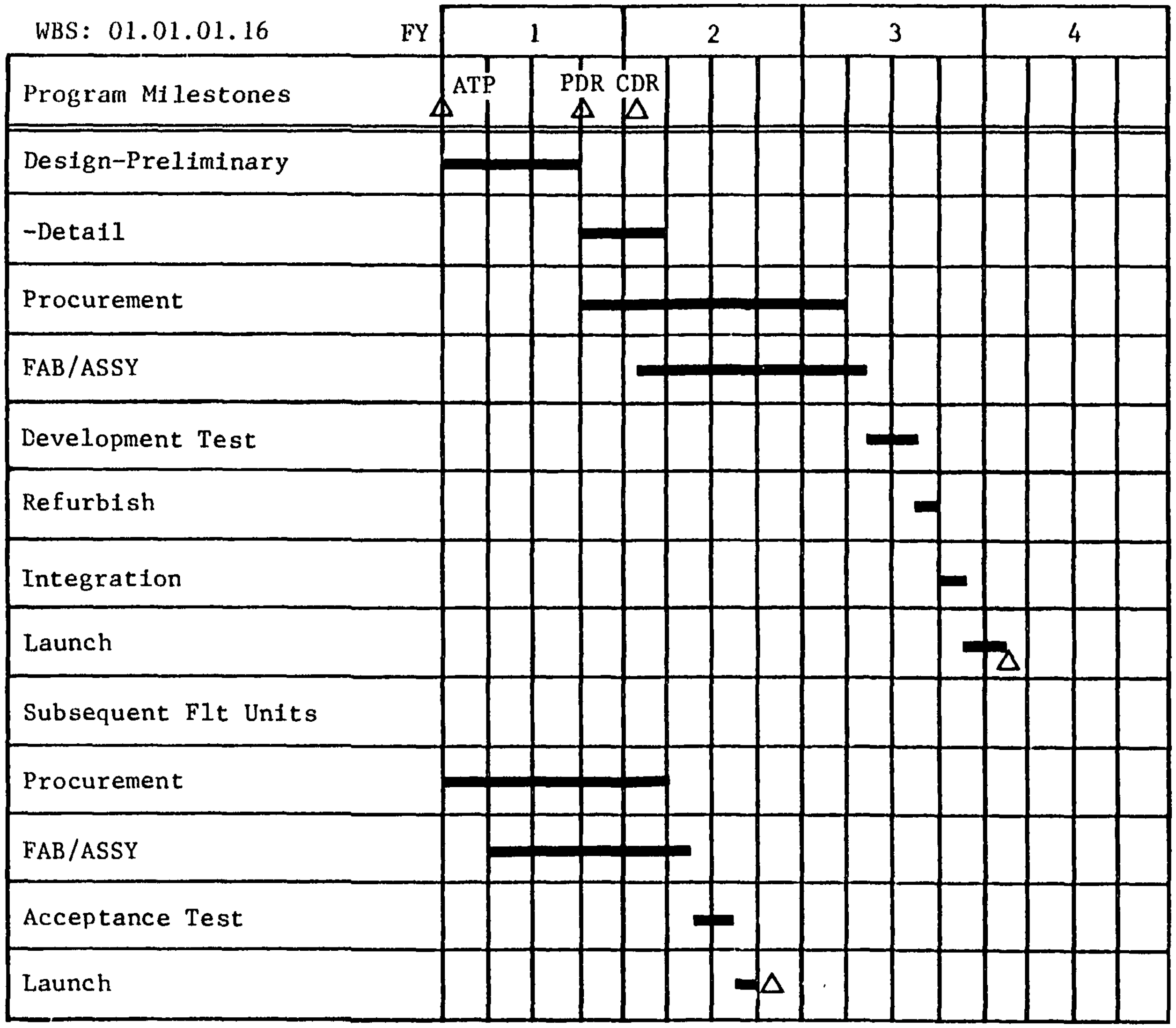


Figure 7.2-7 Space Station Element Schedule-Teleoperator Maneuvering System

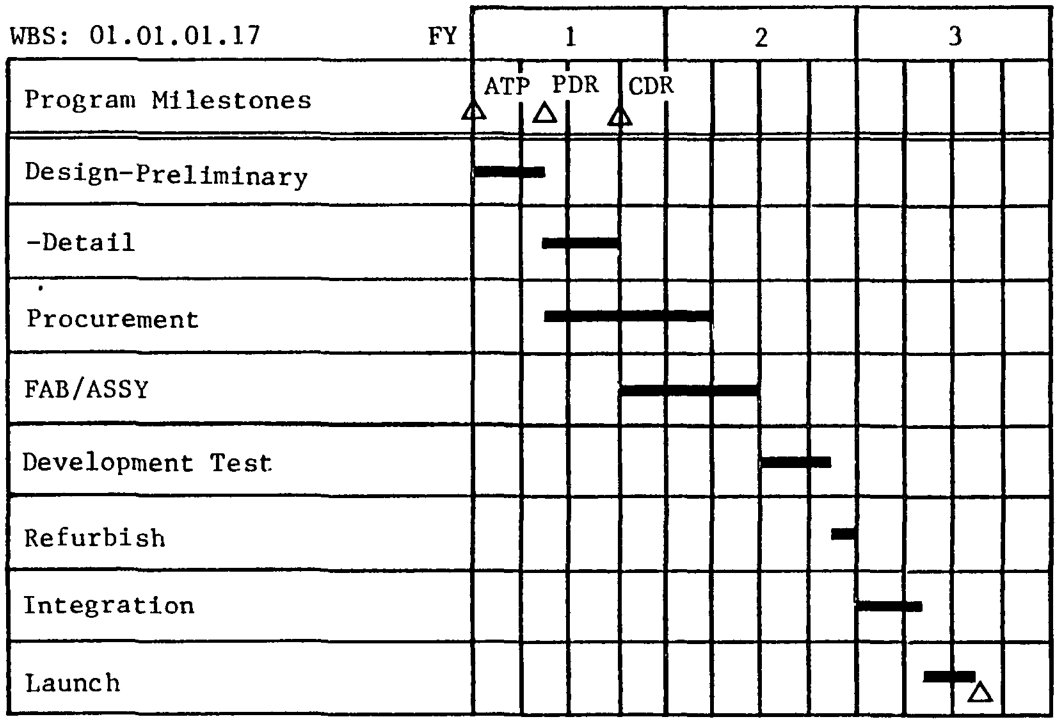


Figure 7.2-8 Space Station Element Schedule-Docking Tunnel

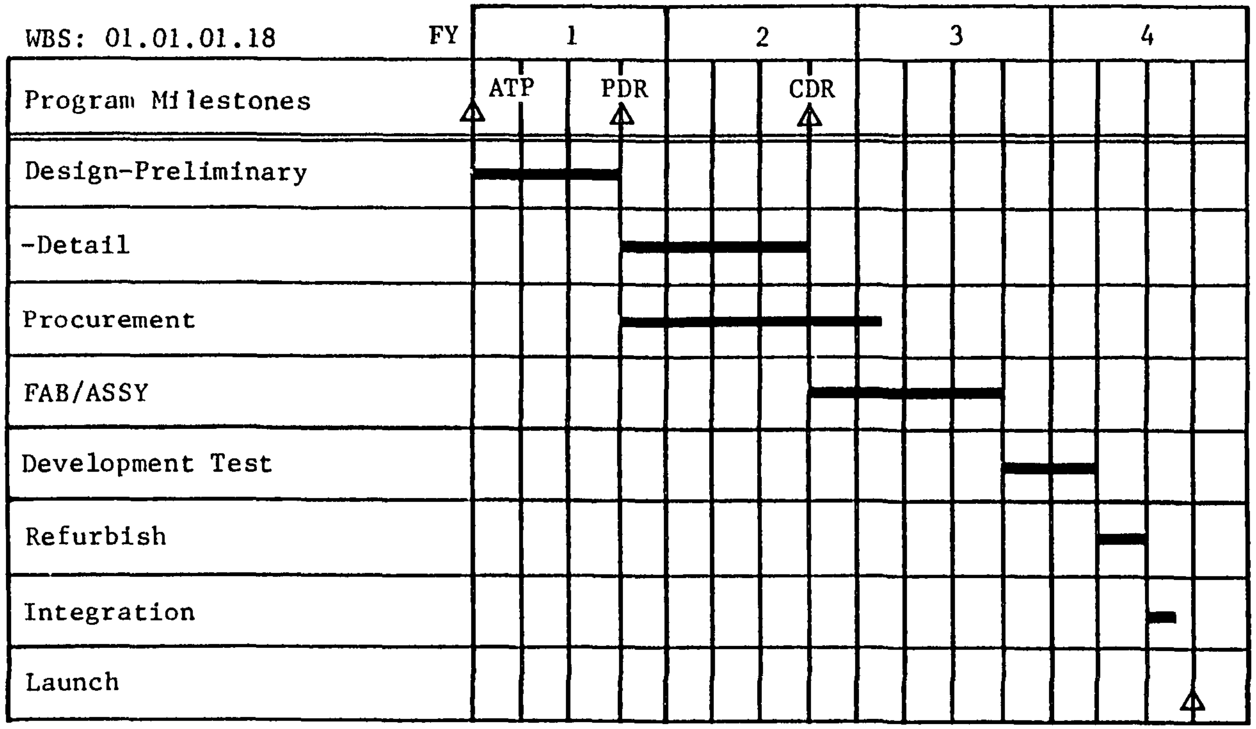
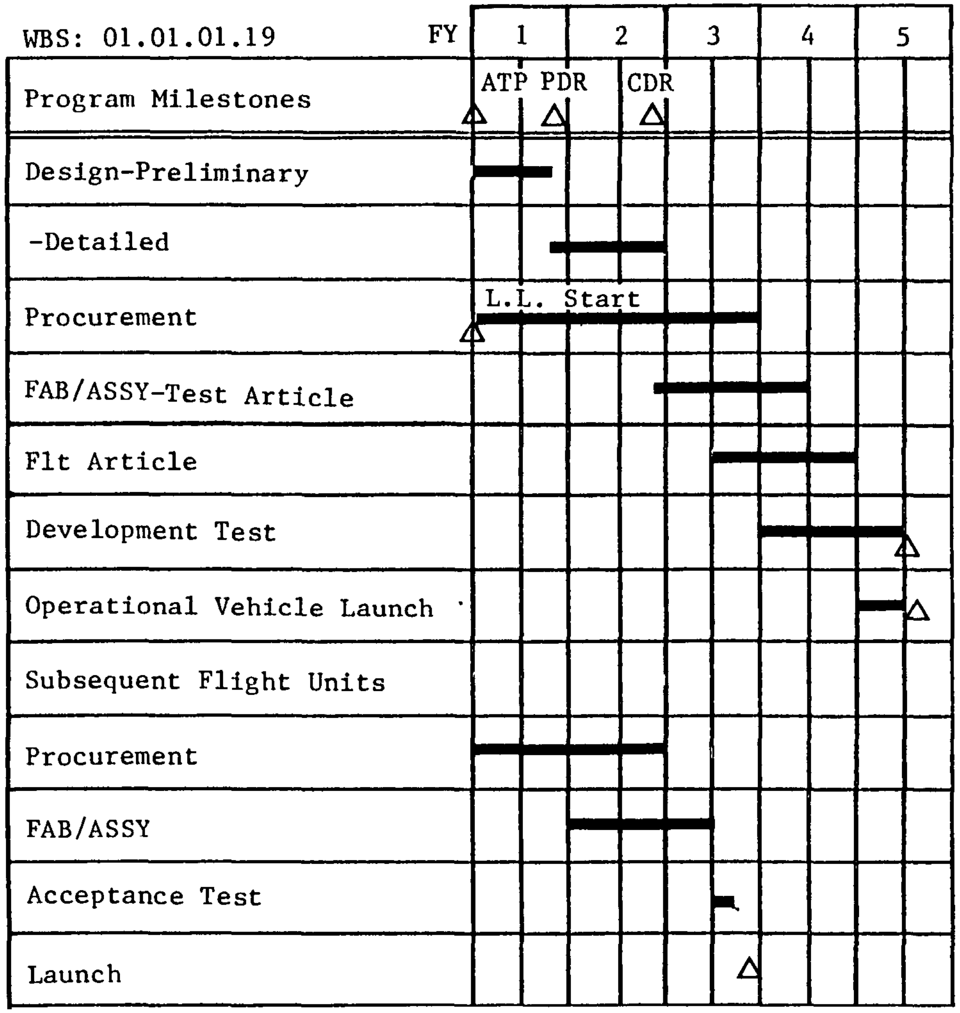


Figure 7.2-9 Space Station Element Schedule-CYRO Storage and Transfer



-Assumes Concurrent Development of Aerobaked OTV

Figure 7.2-10 Space Station Element Schedule-OTV Space Reusable

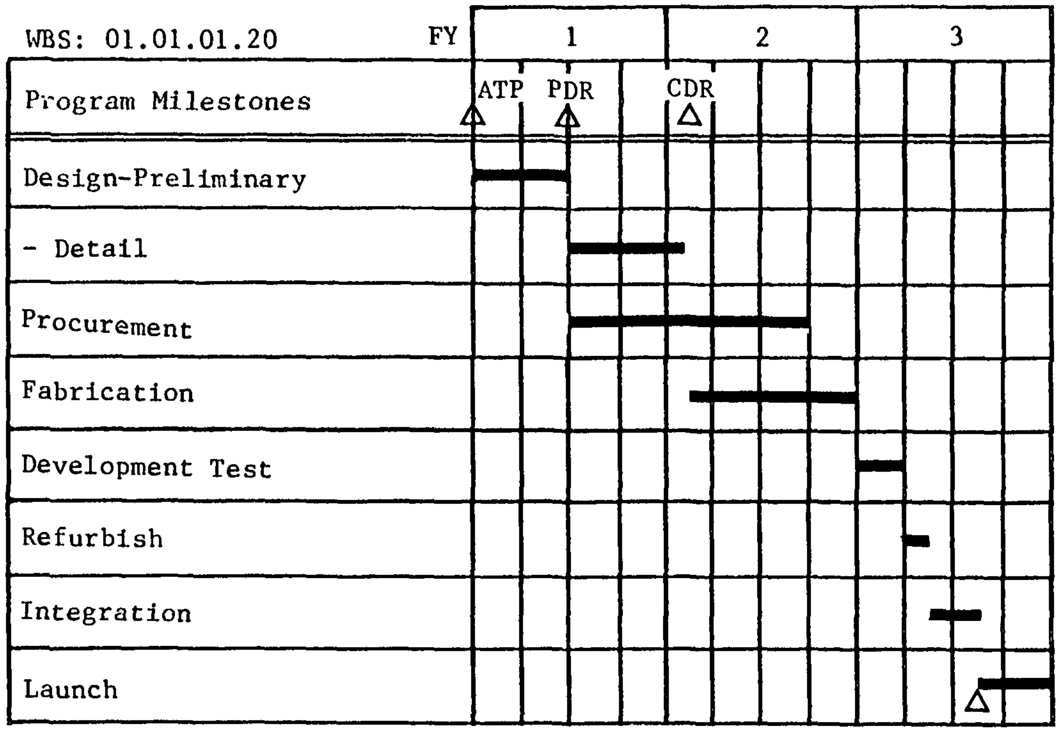


Figure 7.2-11 Space Station Element Schedule-Hangar

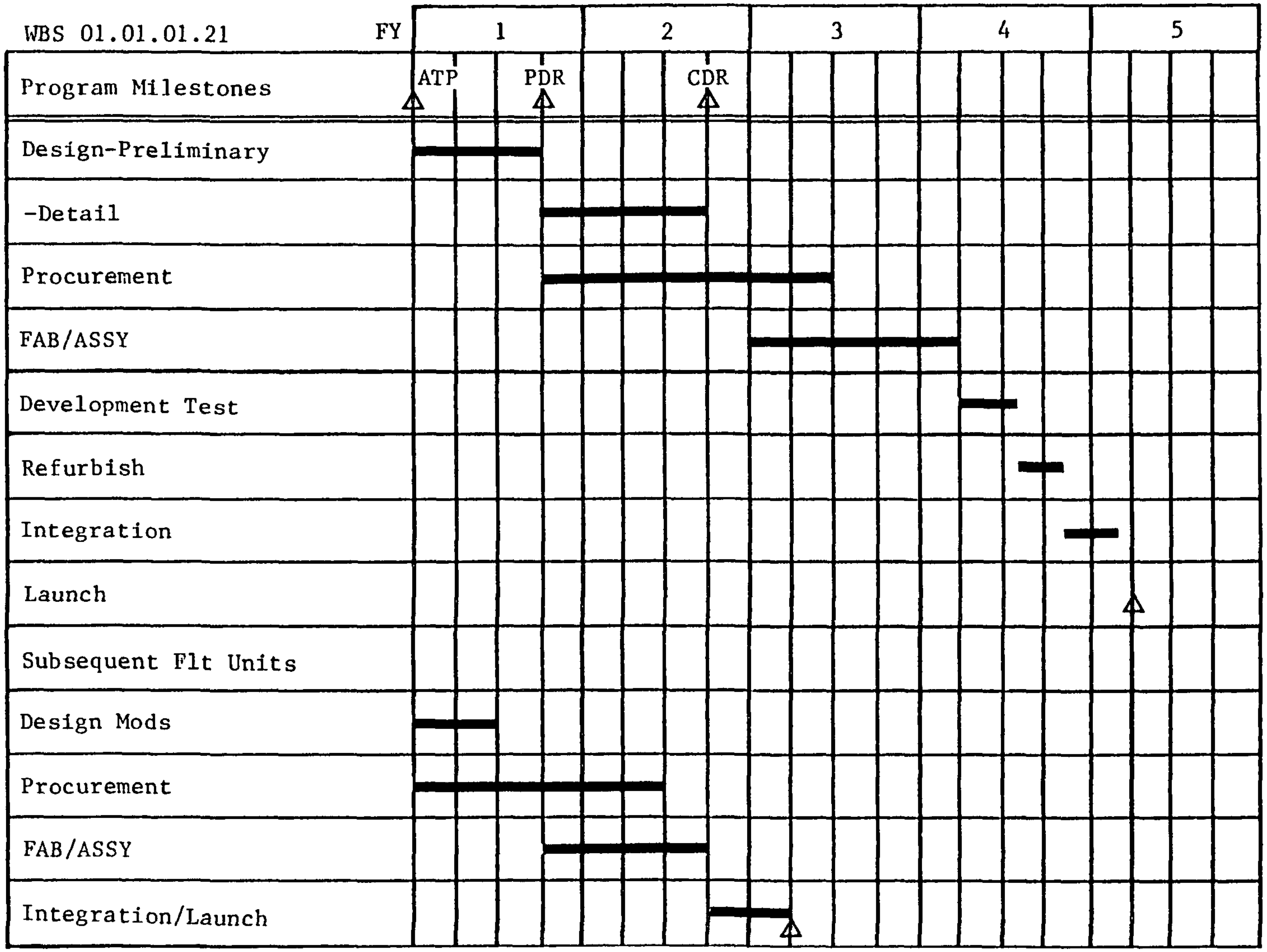


Figure 7.2-12 Space Station Element Schedule-Science Platform

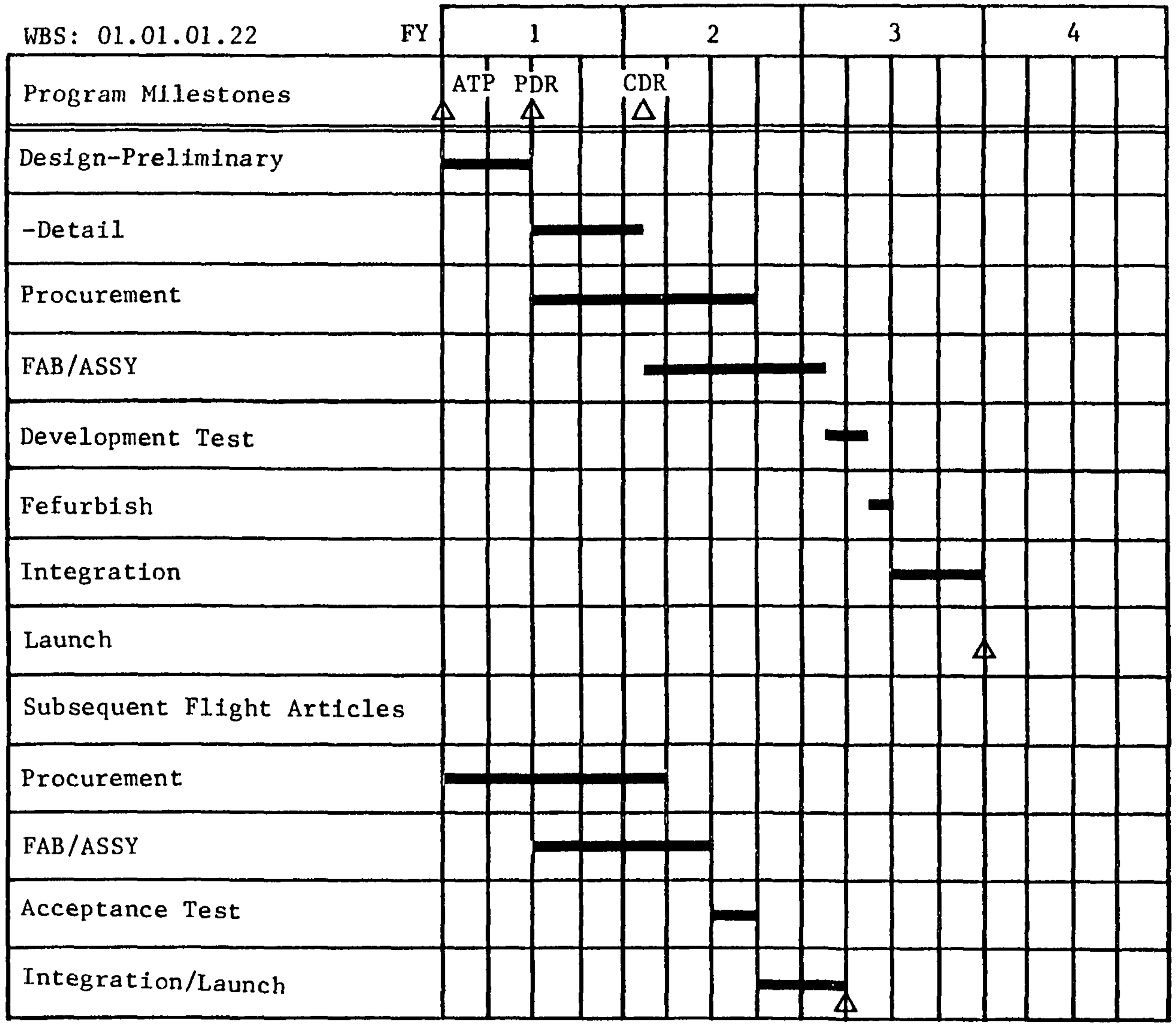


Figure 7.2-13 Space Station Element Schedule-Materials Processing Platform

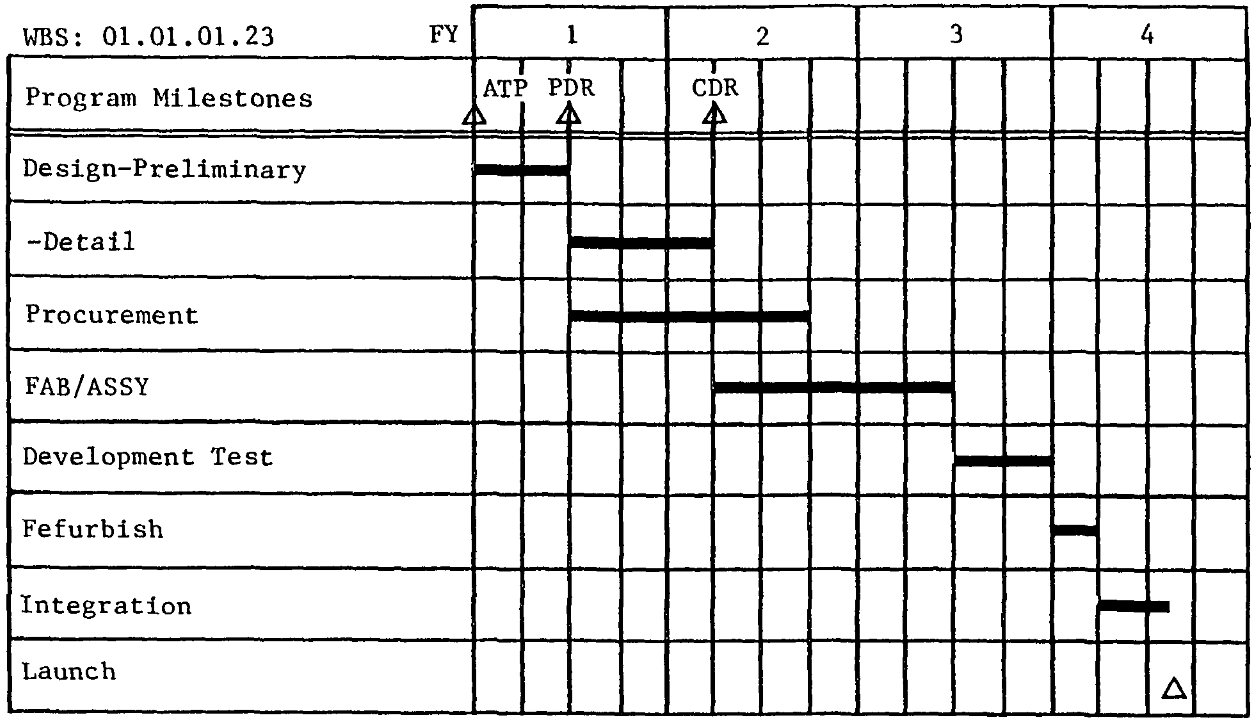


Figure 7.2-14 Space Station Element Schedule-Life Science Research Lab

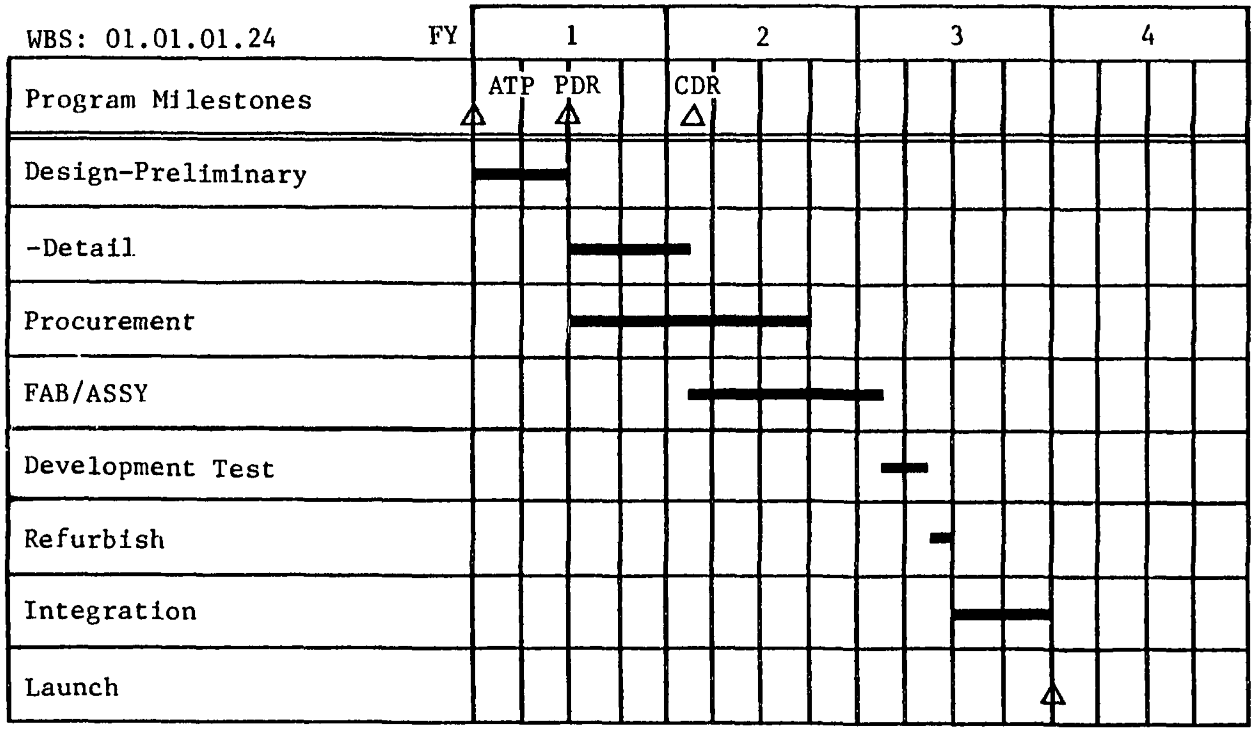


Figure 7.2-15 Space Station Element Schedule-Earth Observation Platform

8.0 RECOMMENDATIONS AND CONCLUSIONS

This programmatics task has presented several major conclusions concerning the development and evolution of a space station.

Its Affordable

We have found that both the acquisition of a space station and the accomplishment of NASAs science and technology objectives are affordable within the projected budget constraints. The affordability analysis was performed to determine an affordable mission set from the total complement of missions that the science community desired to accomplish. The budget constraints necessitated delaying lower priority science missions until funds would be available. The overall effect of including a space station as an orbiting NASA asset is to provide a greater return of science dollar spent by extending on-orbit data collection time.

Its Beneficial

The economic benefits analysis shows that the space station will be cost effective as a space launch base and as a platform for user missions. As a launch base, it has the potential to eliminate the need to buy two additional orbiters that would otherwise be required to handle the projected volume of affordable launches planned in the 1990s. By providing utilities and subsystems to users, the space station will eliminate the need to design and build approximately 40 independent free flying space craft. As an experimental laboratory it will provide low cost continuous time on orbit to shuttle sortie missions that would otherwise be limited to several days on orbit.

The space station as a repair base will enable guick response low cost repair and servicing of satellites to extend their useful life and improve their return on science or investment dollars.

It Pays for Itself

The cost/benefit breakeven analysis indicates that the space station will pay for its acquisition cost in the value it adds to the Space Transportation System. The potential economic advantage as a space transportation node indicates that it can avoid as much as $11.6 billion in FY 1984 dollars. The potential avoidance of each user mission providing their own independent spacecraft bus shows a $3.6 billion advantage to the space station and its associated platforms.

A Reusable OTV Is Needed

Our benefits analysis indicate that a significant advantage of space station is to serve as a launch base for high energy missions. A reusable, space maintained OTV is a necessary element of this scenario to make it cost effective compared to expendable vehicles. The major advantage to a space reusable OTV is that it would not be launched to low earth orbit on each shuttle thus saving space for payloads and reducing total transportation cost to the user.

A Reusable TMS Is Needed

Just as the reusable OTV benefits the transportation of missions to high energy orbits, the TMS vehicle enables delivery and servicing of payloads in orbits near the space station at a significantly reduced cost over a TMS that accompanies shuttle. Again, the major advantage is the launch weight and volume saved if a TMS remains based in orbit at a space station.

Recommendations

We recommend that limited near term NASA funds should be allocated not only to space station technology studies but also to studies to develop on orbit based and maintained, reusable OTV and TMS vehicles. Our study results show these two elements of a space transportation system are necessary to cost effective operation of a space station.

APPENDIX A ACRONYMS AND ABREVIATIONS

A	Angstrom
AC&S	Attitude Control and Stabilization
ACC	Aft Cargo Carrier
ACS	Attitude Control Subsystem
ACTS	Advanced Communications Satellite Corporation
AFB	Air Force Base
AHUT	Animal Holder and Unit Tester
AIAA	American Institute of Aeronautics and Astronautics
AIE	Advanced Interplanetary Explorer
AL	Airlock
ALCOA	Aluminum Company of America
AMIMS	Advanced Meteorological Infrared & Microwave Soander
AMPTE	Active Magnetosphere Particle Tracer Experiment
AO	Announcement Opportunity
AP	Action Potential
ARC	Arnold Research Center
ASE	Airborne Support Equipment
ASO	Advanced Solar Observatory
ASTO	Advanced Solar Terrestrial Observatory
ATP	Authority to Proceed
AXAF	Advanced X-Ray Astrophysics Facility
B	Billion
BASD	Ball Aerospace Division
BCK	Blood Collection Kit
BIT	Built-In Test

APPENDIX A ACRONYMS AND ABREVIATIONS

BITE	Built-In-Test-Equipment
BIU	Bus Interface Unit
BOL	Beginning of Life
BTS	Biotelemetry System
BYU	Brigham Young University
C	Core
c	Centigrade
Ca	Calcium
CB	Cargo Bay
C&DH	Command and Data Handling Subsystem
CDP	Coronal Diagnostic Package
CDR	Critical Design Review
CELSS	Controlled Environment Life Support System
CER	Cost Estimating Relationship
CF	Construction Facility
CG	Center of Gravity
CIT	California Institute of Technology
Cl	Chloride
CLIR	Cryogenics Limb Scanning Interferometer & Radiometer
CM	Command Module
CMD	Command
CMG	Control Moment Gryo
CMM	Composite Mission Model
CO_2	Carbon Dioxide
COBE	*Cosmic Background Explorer*

APPENDIX A ACRONYMS AND ABREVIATIONS

COMPMM	Composite Mission Model
COMSAT	Communications Satellite Corporation
COSMIC	Coherent Optical System Modular Imaging Collector
CR	Comet Rendezvous
CRM	Chemical Release Module
CRMF	Chemical Release Module Facility
CRO	Cosmic Ray Observatory
CRT	Cathode-Ray Tube
CSR	Comet Sample Return
CU	Colorado University
CZCS	Coastal Zone Color Scanner
DBS	Direct Broadcast Satellite
DBV	Derived Boost Vehicle
DDT&E	Design Development, Test and Evaluation
DEMS	Dynamic Environment Monitoring System
DMPS	Data Management and Processing System
DOD	Department of Defense
DRM	Design Reference Mission
DSN	Deep Space Network
DVM	Doctor of Veterinarian Medicine
EAAR	Earth Approaching Asteroid Rendezvous
ECG	Electrocardiograph
ECLS	Environmental Control Pipe Support
ECLSS	Environmental Control/Life Support Systems

APPENDIX A ACRONYMS AND ABREVIATIONS

ECS	Environmental Control System
EEG	Electroencephalogram
e.g.	Example
EKG	Electromyogram
ELS	Eastern Launch Site
EMC	Electromagnetic Compatibility
EMG	Electromyogram
EMI	Electromagnetic Interference
EMU	Extravehicular Mobility Unit
ENG	Electonystagnogram
EOL	End of Life
EOS	Electrophoresis Operations In Space
EOTV	Expendable Orbital Transfer Vehicle
EPS	Electrical Power
EPDS	Electrical Power and Distribution System
ERB	Earth Radiation Budget
ET	External Tank
ETCLS	Environmental and Thermal Control and Life Support
EUVE	Extreme Ultraviolet Explorer
EVA	Extra-Vehicular Activity
Exper	Experimeter
Expmt	Experimeter
fps	Feet per Second
FCC	Federal Communications Commission
FDMA	Frequency-Division Multiple Access

APPENDIX A ACRONYMS AND ABREVIATIONS

FF	Free Flyer
FILE	Feature Identification and Location Experiment
FLOPS	Floating Point Operations Per Second
FOC	Full Operating Capability
FOCC	Flight Operations Control Center
FOT	Faint Object Telescope
FSF	First Static Firing
FUSE	Far Ultraviolet Spectroscopy Explorer
FY	Fiscal Year
g	Gravity
GG	Gravity Gradient
G_Z	Vertical Gravity Acceleration Component
GaAs	Galium Arsemide
GEO	Geosynchronous Earth Orbit
GEOSTO	Geosynchronous Solar Terrestrial Observatory
GFP	Government-Furnished Property
GG	Gravity Gradiometer
GHZ	Gigadertz
GND	Ground
GPS	Global Positioning System
GPWS	General Purpose Work Station
GRIST	Grazing Incidence Solar Telescope
GRO	Gamma Ray Observatory
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center

APPENDIX A ACRONYMS AND ABREVIATIONS

GSS	Ground Support System
GSSI	Geosynchronous Satellite Sensor Intercalibration
GTE	Gamma Ray Timing Explorer
H	Hangar
H_2O	Water
H/W	Hardware
HM	Habitation Module
HMF	Health Maintenance Facility
HNE	Heavy Nuclei Explorer
HOL	Higher Order Language
I&C	Installation and Checkout
I/F	Interface
ID	Identification
INCO	International Nickel Company
INTELSAT	International Telecommunications Satellite Organization
IOC	Initial Operating Capability
IPS	Instrument Pointing System
IR	Infrared
IRAS	Infrared Astronomy Satellite
IRD	Instrument Research Division
IS	Imaging Spectrometer
ISP	Initial Specific Impulse
ISPM	International Solar Polar Mission
ISTO	Initial Solar Terrestrial Observatory
IUE	International Ultra Violet Explorer
IVA	Intravehicular Activity

APPENDIX A ACRONYMS AND ABREVIATIONS

J&J	Johnson and Johnson
JEA	Joint Endeavor Agreement
JHU	John Hopkins University
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
K	Potassium
Kbps	Kilobits Per Second
KG, kg	Kilogram
KSC	Kennedy Space Center
KW, kw	Kilowatt
lbm	Pounds
LAMAR	Large Area Modular Array Reflectors
LAMMR	Large Antenna Multifrequency Microwave Radiometer
LaRC	Langley Research Center
LBNP	Lower Body Negative Pressure
LBNPD	Lower Body Negative Pressure Device
LDR	Large Deployable Reflector
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LIDAR	Light Detection and Ranging
LiOH	Lithium Hydroxide
LM	Logistics Module
LMMI	Large Mass Measurement Instrument
LSEPS	Large Spacecraft Effects on Proximate Space

APPENDIX A ACRONYMS AND ABREVIATIONS

LSLE	Life Sciences Laboratory Equipment
LSLF	Life Sciences Laboratory Facility
LSM	Life Support Module
LSRF	Life Sciences Research Facility
LSRM	Life Sciences Research Module
LSS	Life Support Systems
LRU	Line Replaceable Unit
LWA	Long Wavelength Antenna
mV	Millivolt
M	Million
MAM	Main Belt Asteroid Multirendezvous
Mbps	Megabits Per Second
MD	Medical Doctor
MDAC	McDonnell Douglas Astronautics Company
MeV	Million Electron Volts
MGCM	Mars Geochemistry/Climatology Mapper
MIT	Massachusetts Institute of Technology
MMC	Martin Marietta Corporation
MML	Martin Marietta Laboratories
MMS	Multimission Modular Spacecraft
MMU	Manned Maneuvering Unit
MOHM	Megaohms
MOTV	Manned Orbital Transfer Vehicle
MP	Materials Processing
MPN	Mars Probe Network

APPENDIX A ACRONYMS AND ABREVIATIONS

MPS	Materials Processing in Space
MR	Microwave Radiometer
MRICD	Medical Research Institute for Chemical Defense
MRWS	Mobile Remote Work Station
M-SAT	Mobile Satellite
MSFC	Marshall Space Flight Center
MWPC	Multi-Wire Proportional Counter
MWS	Microwave Sounder
N/A	Not Applicable
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NiH_2	Nichel Hydrogen
NM	Nautical Miles
NMR	Nuclear Magnetic Resonance
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
ODSRS	Orbiting Deep Space Relay Station
OIST	Orbiting Infrared Submillimeter Telescope
OMP	Ocean Microwave Package
OMS	Orbital Maneuvering Systems
O_2	Oxygen
O_2/N_2	Oxygen/Nitrogen
OPEN	Origin of Plasma in the Earth Neighborhood
OSA	Optical Society of America
OTV	Orbital Transfer Vehicle
OVLBI	Orbital Very Long Baseline Interferometer

APPENDIX A ACRONYMS AND ABREVIATIONS

P	Phosphorous
PDR	Preliminary Design Review
PET	Position Emission Tomography
PhD	Doctorate of Philosophy
PH	Level of Acidity
PI	Principal Investigator
PIDA	Payload Installation and Deployment Aid
P/L	Payload
PLSS	Portable Life Support Systems/Personal Life Support System
PMD	Propellant Management Device
PMS	Physiological Monitoring System
P/OF	Pinhole/Occulter Facility
PS	Payload Specialist
psi	Pounds per Square Inch
psia	Pounds per Square Inch Absolute
PTE	Plasma Turbulence Explorer
QD	Quick Disconnect
R&D	Research and Development
R&T	Research and Technology
RAHF	Research Animal Holding Facility
RBC	Red Blood Cell
RCA	Radio Corporation of America
RCS	Reaction Control System
REM	Roentgen Equivalent, Mass

APPENDIX A ACRONYMS AND ABREVIATIONS

RF	Radio Frequency
RFP	Request for Proposal
RMS	Remote Manipulator System
ROM	Rough Order of Magnitude
ROSS	Remote Orbital Servicing System
ROTV	Reusable Orbital Transfer Vehicle
SAO	Smithsonian Astronomical Observeratory
SAR	Synthetic Aperture Radar
SARSAT	Search and Rescue Satellite - Aided Tracking
SAT	Satellite
S/C	Spacecraft
SCADM	Solar Cycle and Dynamics Mission
SCDM	Solar Coronal Diagnostic Mission
SCE	Solar Corona Explorer
SDCV	Shuttle Derived Cargo Vehicle
SDV	Shuttle Derived Vehicle
SERV	Servicing
SEXTF	Solar EUV/XUV Telescope Facility
SHEF	Solar High Energy Facility
SIDM	Solar Interior Dynamics Mission
SIDF	Solar Interior Dynamics Facility
SIRTF	Shuttle Infrared Telescope Facility
SIS	Solar Interplanetary Satellite
SL	Spacelab
SLFRF	Solar Low Frequency Radio Facility

APPENDIX A ACRONYMS AND ABREVIATIONS

SMMI	Small Mass Measurement Instrument
SOMS	Shuttle Orbiter Medical Systems
SO/P	Saturn Orbiter/Probe
SOT	Solar Optical Telescope
SP	Scientific Payload
SPELS	Space Plasma Effects on Large Spacecraft
SPIE	Society Photo-Optics Instrument Engineers
SRB	Solid Rocket Booster
SRR	Systems Requirements Review
SS	Space Station
SSCAG	Space System Cost Analysis Group
SSEC	Solar Systems Exploration Committee
SSF	Solar Shuttle Facility
SSL	Space Sciences Laboratory
SSMM	Space Station Mission Model
SSR	Solar Spectrometer/Radiometer
SSRMS	Space Station Remote Manipulator System
SSXTF	Solar Soft X-Ray Telescope Facility
ST	Space Telescope
STDN	Space Tracking and Data Network
STO	Solar Terrestrial Observatory
STS	Space Transportation System
SVI	Stereo Visual Image
TAT	Thinned Aperture Telescope
TBD	To Be Determined
TBR	To Be Required

APPENDIX A ACRONYMS AND ABREVIATIONS

TBS	To Be Supplied
TCS	Thermal Control Subsystem
TDAS	Tracking and Data Acquisition System
TDM	Technology Development Mission
TDMA	Time-Division Multiple Access
TDRS	Tracking and Data Relay Satellite
TDRSS	TDRS System
TEM	Transmission Electron Microscopy
THM	Tethered Magnetometer
TIMI	Thermal Infrared Multispectral Imager
TM	Technical Memorandum
TMS	Teleoperator Maneuvering System
TOPEX	Ocean Topography Experiment
TP	Thermal Panels
TPS	Thermal Protection System
TSS	Time Sharing System
TV	Television
um	Micrometer = micron
usec	Microsecond
uvolt	Microvolt
UARS	Upper Atmosphere Research Satellite
UC	University of California
UCSF	University of California, San Francisco
UHF	Ultra High Frequency

APPENDIX A ACRONYMS AND ABREVIATIONS

Ult	Ultimate
UM	University of Maryland
UM	University of Michigan
UMS	Urine Monitoring System
U.S./USA	United States/United States of America
US	Upper Stage
USRA	University Space Research Association
UT	University of Texas
UV	Ultraviolet
V	Velocity
VAP	Venus Atmospheric Probe
VAFB	Vandenberg Air Force Base
VCU	Virginia Commonwealth University
Vdc	Volts Direct Current
VFR	Vestibular Function Research
VHEO	Very High Earth Orbit
VHSIC	Very High Speed Integrated Circuit
VLR	Very Large Radar
VLST	Very Large Space Telescope
VRF	Vestibular Research Facility
VRM	Venus Radar Mapper
WARC	World Administration Radio Conference
WBS	Work Breakdown Structure
WLS	Western Launch Site
WRU	Work Restraint Unit

APPENDIX A ACRONYMS AND ABREVIATIONS

XGP	Experimental Geostationary Platform
XRO	X-Ray Observatory
XTE	X-Ray Timing Explorer
Zero g	Zero Gravity
β angle	Angle Between Orbit Plane and Solar Vector
α_s	Coating Solar Absorptance
ε	Coating Emmitance
ω	Watts

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B REFERENCES

A. National Academy of Sciences

Astronomy and Astrophysics for the 1980's - January 1982.

B. Unamnned Spacecraft Cost Model, U. S. Air Force, Space Division, Fifth Edition, June 1981.